AD-A086 130 GENERAL ELECTRIC CO CINCINNATI OH AIRCRAFT ENGINE GROUP F/G 21/5

F101 CENTRAL INTEGRATED TEST SUBSYSTEM EVALUATION.(U)

FEB 80 C T VINCENT, C A ARULF F33615-79-C-2022

UNCLASSIFIED R79AEG622 AFWAL-TR-80-2002 NL

1 OF 2

AD
A086130

(2) LEVEL II

AFWAL-TR-80-2002

F101 CENTRAL INTEGRATED TEST SUBSYSTEM EVALUATION

GENERAL ELECTRIC

FEBRUARY 1980

TECHNICAL REPORT AFWAL-TR-80-2002
FINAL REPORT FOR PERIOD 2 APRIL 1979-31 DECEMBER 1979
APROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

AERO PROPULSION LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT PATTERSON AIR FORCE BASE, OHIO

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

JOSEPH J. BATKA
Project Engineer
Components Branch
Turbine Engine Division

DAVID H. QUICK, Lt Col, USAF
Chief, Components Branch
Turbine Engine Division

FOR THE COMMANDER

E. C. SIMPSON
Director
Turbine Engine Division

"If your address has changed, if you wish to be removed from our mailing list, or if the addressee is no longer employed by your organization please notify AFWAL/POTC, ***W-PAFB, OH 45433 to help us maintain a current mailing list".***

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

AIR FORCE/56780/24 June 1980 — 50

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFWAL-TR-80-2002	2. GOVT ACCESSION NO.: AD-A086 130	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): F101 Central Integrated Test Subsystem Evaluation Final Report		5. TYPE OF REPORT & PERIOD COVERED: Final Technical Report - 4/2/79 - 12/31/79
		6. PERFORMING ORG. REPORT NUMBER: R79AEG622
7. AUTHOR(s): C.T. Vincent, C.A. Arulf		8. CONTRACT OR GRANT NUMBER(s): F33615-79-C-2022
9. PERFORMING ORGANIZATION NAME AND ADDRESS: General Electric Company, Aircraft Engine Group, Cincinnati, Ohio 45215		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62203F, 366-1.3-3.0
11. CONTROLLING OFFICE NAME AND ADDRESS: Aero Propulsion Laboratory (POTC), Air Force Wright Aeronautical Laboratories, Wright-Patterson AFB, Ohio 45433		12. REPORT DATE: February 1980
		13. NUMBER OF PAGES: 136
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report): Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

"This program was funded with FY 79 Aero Propulsion Laboratory Director's Funds."

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Engine Condition Monitoring, Diagnostics, Fault Detection, Fault Isolation, Trending

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Existing B-1/F101 flight data were used to determine the technical application and results of the diagnostic and monitoring systems utilized in the CITS. Contractor's analyses performed in support of the B-1 program provide the starting point for this program. The CITS functions investigated were (1) fault detection and isolation, (2) flight readiness status, (3) LCF and time at temperature counting, and (4) trend data acquisition. The data evaluation had four objectives: (1) Determine how well the B-1/F101

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

4 4 1

diagnostic and monitoring requirements/goals were met; (2) establish the rates of false indication; (3) categorize the maintenance actions taken on the basis of CITS inputs; and (4) determine the effectiveness of the trending program. In addition, the effectiveness of the F101 CITS parameter and data sampling rates was determined. Continuous recorded CITS data were used to evaluate usage tracking parameters and their effectiveness in determining maintenance actions.

TABLE OF CONTENTS

TABLE OF CONTENTS (Concluded)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Concluded)

LIST OF TABLES

SECTION I

INTRODUCTION

This report documents the effectiveness of the B-1/F101 Central Integrated Test Subsystem (CITS). The CITS was developed as a weapons system condition monitoring system during the course of the B-1 Flight Test Program. This program began in December 1974 with the first flight of the B-1 and will continue through September 1980. This report pertains only to the engine portion of the CITS.

This report fulfills the requirements of USAF Contract No. F33615-79-C-2022 granted in response to an unsolicited Proposal No. P78-147, "F101 Central Integrated Test Subsystem Evaluation," by the General Electric Company, Aircraft Engine Group, Advanced Engineering and Technical Programs Department, Cincinnati, Ohio 45215.

A. REPORT OBJECTIVES

The principal objective of this report is to evaluate the B-1/F101 Central Integrated Test Subsystem (CITS) using the existing F101 flight data base. This data base consisting of approximately 4600 engine flight hours represents an existing comprehensive source of diagnostic information on afterburning turbofan engines. The secondary objective of this report is to provide a quantified base with recommendations for evaluation of future afterburning turbofan engine diagnostic/monitoring systems.

B. SCOPE

Existing B-1/F101 flight data were used to determine the technical application and results of the diagnostic and monitoring systems utilized in the CITS. Contractor's analyses performed in support of the B-1 program provide the starting point for this program. The CITS functions investigated were: (1) Fault detection and isolation, (2) flight readiness status, (3) LCF and time at temperature counting, and (4) trend data acquisition. The data evaluation had four objectives: (1) Determine how well the B-1/F101 diagnostic and monitoring requirements/goals were met; (2) establish the rates of false indication; (3) categorize the maintenance actions taken on the basis of CITS inputs; and (4) determine the effectiveness of the trending program. In addition, the effectiveness of the F101 CITS parameter and data sampling rates was determined.

Continuous recorded CITS data were used to evaluate usage tracking parameters and their effectiveness in determining maintenance actions.

SECTION II

CITS DESCRIPTION

A. GENERAL DESCRIPTION

The air vehicle Central Integrated Test Subsystem (CITS) continually tests the operability of all air vehicle subsystems. Besides displaying malfunction data to the air crew for evaluation of mission capability, the CITS records and displays data for ground crews to facilitate air vehicle maintenance. It is composed of: (1) A digital computer with a software program which processes data to determine the operational status of subsystems, (2) data acquisition units for interfacing air vehicle subsystems to provide the computer with accessible data, (3) the CITS Control and Display (CCD) for the person/machine interface, (4) a clear test printer to provide immediate postflight maintenance data, and (5) a magnetic tape digital recorder to provide overall maintenance data for ground processing equipment. This report addresses only the engine portion of the CITS.

B. AIRCRAFT CITS HARDWARE CONFIGURATION

The CITS hardware configuration for Aircraft 1 and 2 is shown in Figure 1. The hardware consists of a computer, display panel, recorder, and printer. For Aircraft (A/C) 3 and 4, the only additional interface is the avionics computer; A/C 4 CITS computer has a larger memory capacity (64,000 words versus 49,000 on A/C 1 through 3). The control and display panel is illustrated in Figure 2.

For the Flight Test Program, engine CITS data from the CITS computer were also recorded on the flight test data recorder (not shown here) at the rate of one sample every 5 seconds except when interrupted by the envelometer on A/C 3 and 4.

C. CITS FUNCTIONAL SCHEMATIC

Figure 3 illustrates the CITS top level functional schematic.

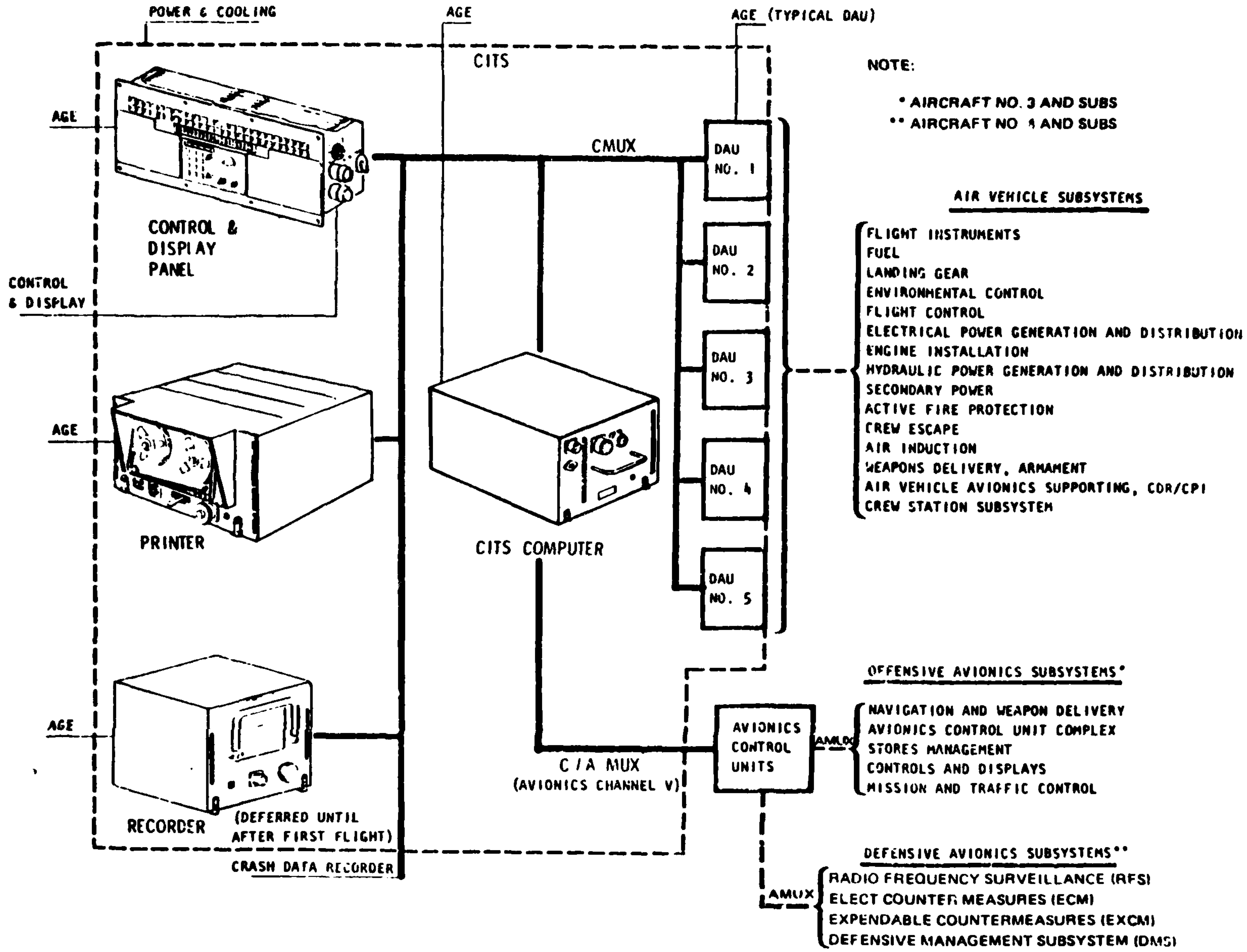


Figure 1. CITS Configurations.

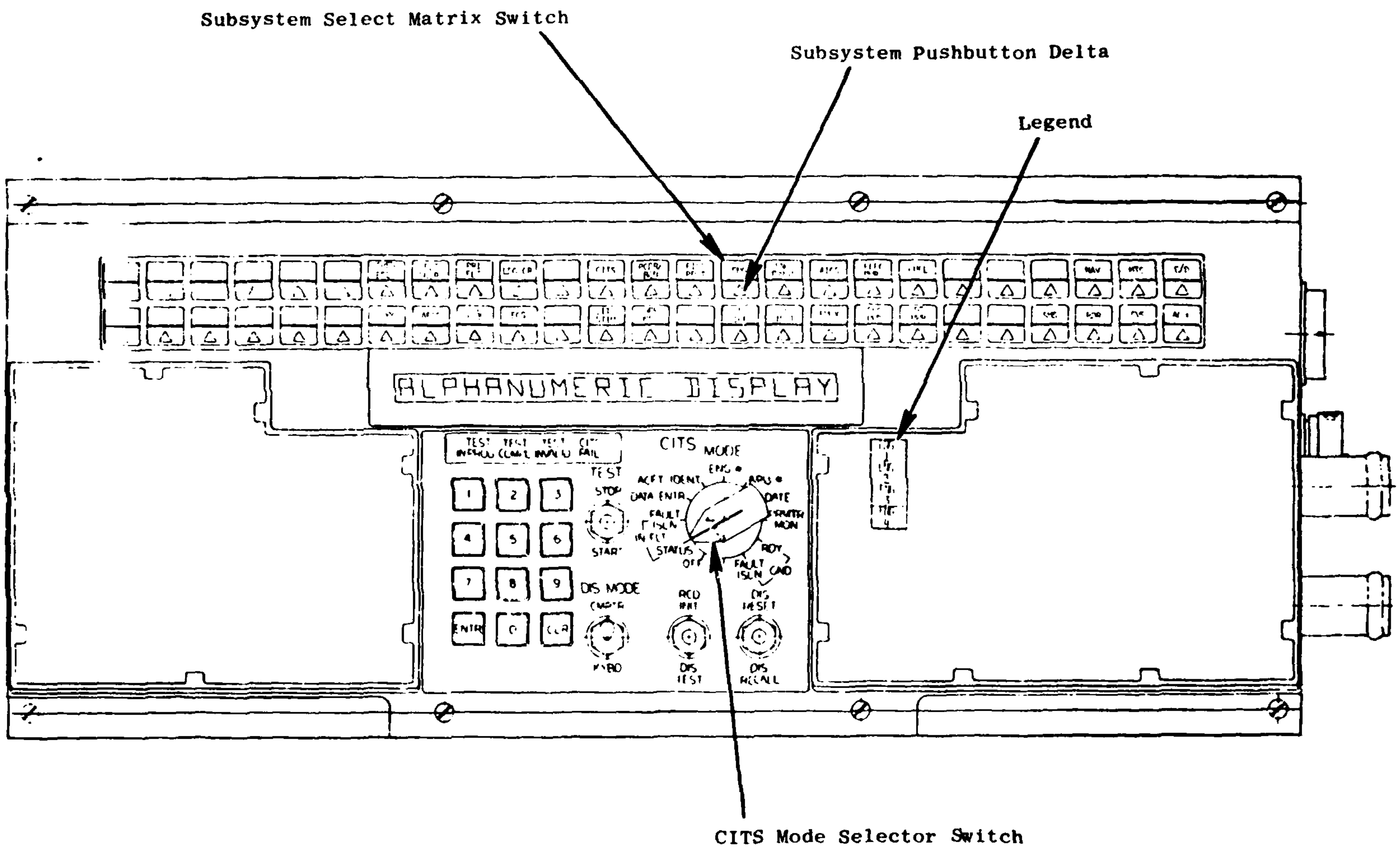


Figure 2. CITS Control and Display Panel.

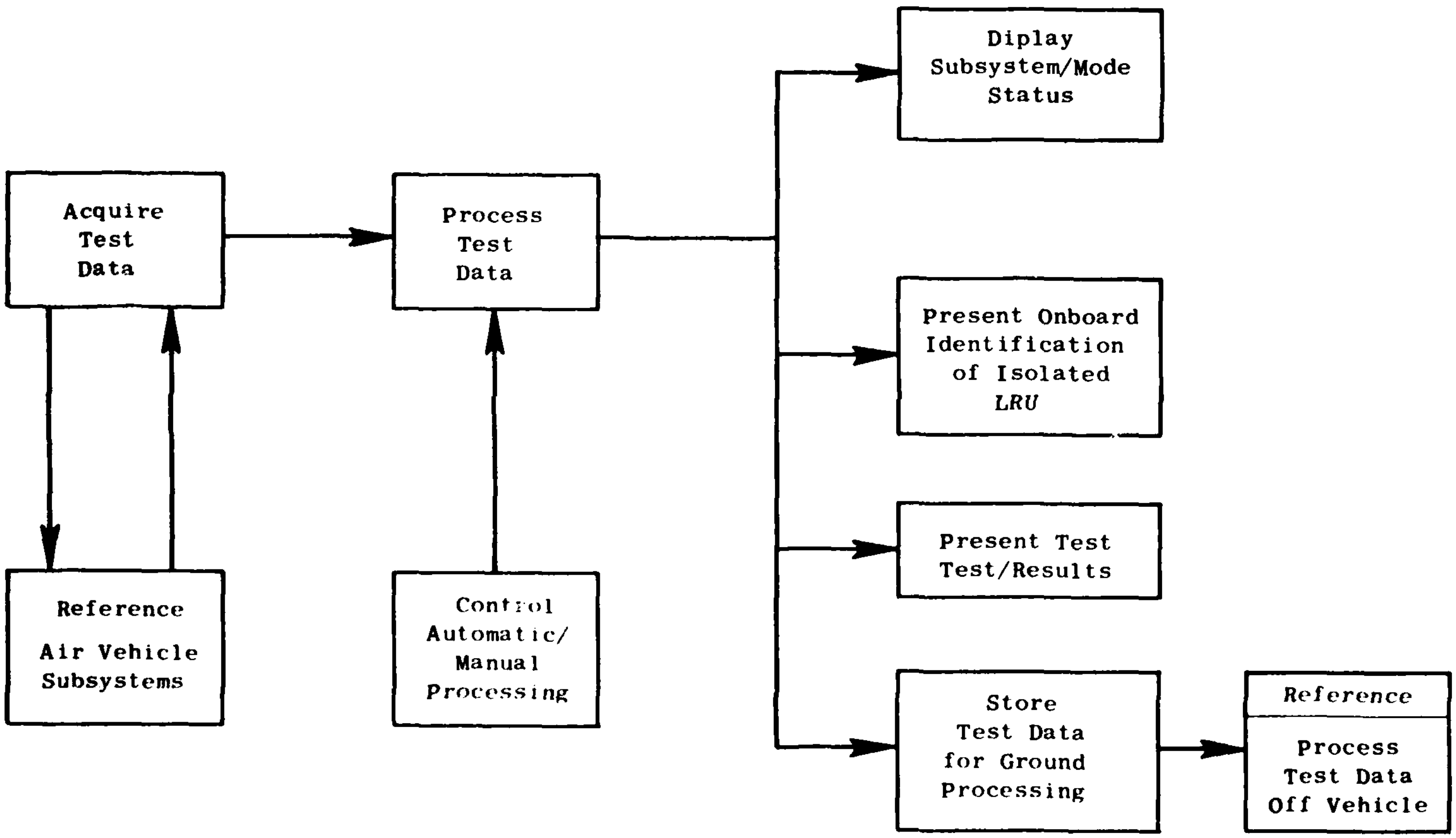


Figure 3. CITS Top Level Functional Schematic.

D. CITS/PERSON INTERFACE

CITS/person interface is accomplished through the CITS Control and Display (CCD) panel located at the flight engineer's station in the air vehicle. The CCD is used to input information into the system and receive information from the system. Upon entering the A/C, the Flight Test Engineer starts up and initializes the CITS system. This initialization procedure includes inputting certain data using the 12-button numeric keyboard. In the case of the engine subsystem, this consists of engine serial number (S/N) and position, the A/C tail number, and the flight number. Additionally, the data and time (GMT or "ZULU") are also input.

When a fault is detected on the ground or in flight, the engine position light on the CCD lights up, as do the master caution light at the pilot's station and the engine subsystem light. When the engine subsystem light/button is acknowledged, the alphanumeric message associated with a fault appears on the CCD alphanumeric display. The fault message and time are also printed on the maintenance paper tape printer. The system is automatically reset when a fault is acknowledged. That particular fault on that engine position is "locked out" unless the CITS is shut down and reinitialized so that it will not continue to annunciate if the fault should remain or reappear.

E. ENGINE CITS PROCESSOR (CITSP)

The CITSP mounted on the engine receives recording signals expressed in d.c. voltage levels. These voltages represent levels of pressure, temperature, speed, area, current, and position. In addition to these signals, the CITSP receives pressure signals and incorporates pressure transducers to convert these to electrical signals. The CITSP scales each of these electrical signals to a nearly common level and converts them to a serial digital signal format for transmission to the air vehicle CITS Data Acquisition Unit (DAU) via a data bus. An air vehicle signal is used to address the individual parameter channels to obtain the outputs desired from the CITSP. Included in the CITSP output channels are three "check words" that are used as part of the system self-test.

F. ENGINE CITS PROCESSOR AND INSTRUMENT SUBSYSTEM SIGNALS

Tables 1 and 2 represent engine CITS parameters and the abbreviated symbols that are used herein to represent them.

G. AIRCRAFT PARAMETER/INFORMATION REQUIRED FOR ENGINE CITS

Table 3 shows aircraft-supplied information required by the engine CITS test algorithms.

H. SCDU/EMU/CITS INTERFACE DESCRIPTION

Twelve signals are hardwired through the engine/air vehicle interface plug for each of the four engines to the signal conditioning and distribution unit (SCDU) of the engine instruments subsystem (EIS) from engine-mounted sensors/transducers provided with the engine. These sensors are for fan rpm, core rpm, nozzle position, turbine blade temperature, engine exhaust gas temperature, lube oil pressure, lube oil temperature, lube oil quantity, fan discharge pressure, and three engine vibration sensors. The engine core fuel flow sensor is furnished as part of the EIS and is engine-mounted. The airframe fuel flow sensor and fuel inlet temperature sensor are provided as part of the EIS and are airframe-mounted. The fan inlet pressure sensor (PT2), furnished as separate equipment, is engine-mounted and is processed by the SCDU.

The SCDU also supplies excitation to eight of the aforementioned sensors: oil pressure, oil temperature, oil quantity, fan discharge pressure, core fuel flow, airframe fuel flow, fuel inlet temperature, and fan inlet pressure.

The signals received by the SCDU are filtered and processed into normalized (0.25 to 4.75) d.c. voltage which is sent to redundant channel computation and distribution electronics. After each signal is processed, it is transmitted in serial-binary form from the SCDU to EMUX upon receiving a serial-binary address from EMUX. EMUX transmits these redundant data to the left and right EMUX channels, to the indicators in the front cockpit, and to CITS via a CITS interface (CI) box. Some of the signals outputted by the SCDU to EMUX are for CITS use only (for engine testing and trending); these

Table 1. Engine CITS Processor Signals.

Nomenclature	Abbreviation
Fan inlet temperature	T2
Fan rpm	NF
A8 actuator position	A8
Duct pressure ratio	$\Delta P/P$
Inlet guide vane position	BF
Power lever angle	PLA
A8 torque motor current	A8TM
WFR torque motor current	WFRTM
MF torque motor current	MFTM
IGV torque motor current	IGVTM
Augmentor pressure switch position	PAUGSW
Augmentor fuel valve position	WFR/PS3
Compressor discharge pressure	PS3
Augmentor fuel pressure	PWFR
*Flame detector	FDS
Check word A	CWA
Check word B	CWB
Check word C	CWC

Notes:
1. Signals are used for test and isolation mode in flight and on the ground.
2. Signals are serial digital (base 10) and sampled four times per second.

*F101-GE-100 Only

Table 2. Engine Instruments Subsystem Signals.

Nomenclature	Abbreviation
Core rpm	NC
Core fuel flow	CFF
Fan rpm	NF
Fan inlet pressure	PT2
Fan discharge pressure	PT25
Oil pressure	PL
Oil quantity	QL
Oil temperature	TL
Fuel flow	FF
Airframe fuel flow	AFF
Nozzle position	A8
Turbine blade temperature (Note 4)	T4B
Forward vibration	FWDVIB
Forward fan vibration	FWDFVIB
Midvibration	MIDVIB
Midfan vibration	MIDFVIB
Midcore vibration	MIDCVIB
Aft vib	AFTVIB

Notes:
1. Signals are used for test and isolation mode in flight and on the ground.
2. Signals are serial digital (base 10) and sampled four times per second.
3. Signals are acquired by CITS from A/V EMUX.
4. The T5 thermocouple signal is substituted for T4B when engine temperature as measured by the pyrometer is below 700° C.

Table 3. Aircraft Parameter/Information Required for Engine CITS.

Nomenclature	Abbreviation
Anti-ice Switch Position	AISP
Start, Start	ENG STRT
Start, Stop	ENG STOP
Engine Ignition, Continuous Position	---
Engine Ignition, Off Position	---
Speed Lockup	---
Condition Reset	---
Anti-icing System Demand	
Airflow Limit Signal	
Aircraft On-ground Status	
Secondary Power System Status	
Thrust Control Position	
Engine Throttle Control System Error	
Fuel Inlet Temperature	TF
Inlet Control System Status	
Date	
Time	
Aircraft No.	
Engine Serial No.	S/N
Engine Position	E1,E2,E3,E4
LCF Cycles (computed from NF, NC, P_{S3}, and T_{4B})	
Overspeed - Time Versus NF and NC	
Overtemp - Time Versus T_{4B}	
CITS Thrust (calculated)	
Fault Detection/Isolation Output (from engine CITS logic)	

NOTES 1. Signals are acquired by CITS from A/C EMUX.

2. PLA LCF cycles are substituted for P_{S3} LCF cycles on flights after 4-12.

will appear only on the left side of EMUX. Table 2 lists the signals used from the EIS.

I. ENGINE SCHEDULE USAGE

The CITS engine test is divided mainly into two portions: transient and steady state. It is during the steady-state portion that the engine control schedules are used in the test. For example, Figure 4 represents a schedule of percent fan speed versus inlet temperature. This relationship is used to determine what fan speed limit is permitted for the current inlet temperature level.

The use of the schedules in the CITS engine test is as follows:

- All schedules are broken down into straight-line equations (slope, intercept format) and programmed into the computer, either in the main execution line or as reusable subroutines.
- In the logic diagrams, many logic decision blocks feature expressions like: "Is NC < NCREF-2%." The engine test includes a technique to calculate the reference core speed (NCREF) as a function of PLA, NF and inlet temperature. After the NCREF value is calculated, 2% of that value would be subtracted and the result would be compared directly to the measured NC signal. Schedules are checked by comparing a measurable value to a precalculated limit. This technique is used throughout the steady-state testing of the engine.

Although the engine control system schedules are not used in the transient engine test, certain parameters (such as vibration) have limit schedules which are used in the transient test. Figure 5 shows a typical limit schedule. This schedule shows the relationship between the midfan/rev vibration level and the fan speed for which that level is the limit of the transient test.

J. ENGINE TRENDING REQUIREMENTS AND RECORDING CAPABILITIES

Table 4 represents the parameters selected to trend the F101 engine.

The following paragraphs list the total recording capabilities required of the engine test portion of CITS.

T2 ~ R	NF ~ %
415	90.27
510	99.27
555	99.27
640	96.67
845	79.67

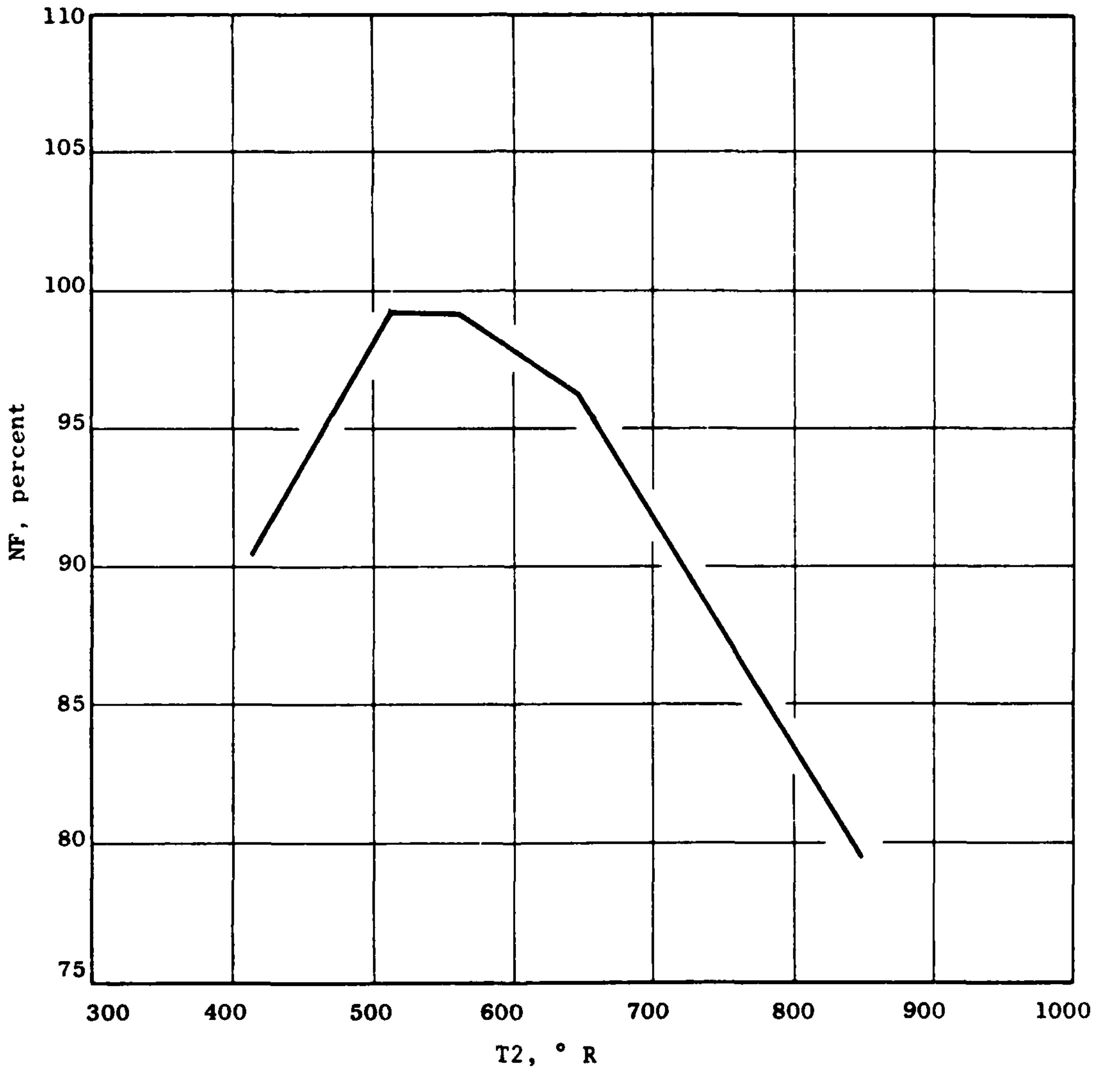


Figure 4. NF Limit Schedule.

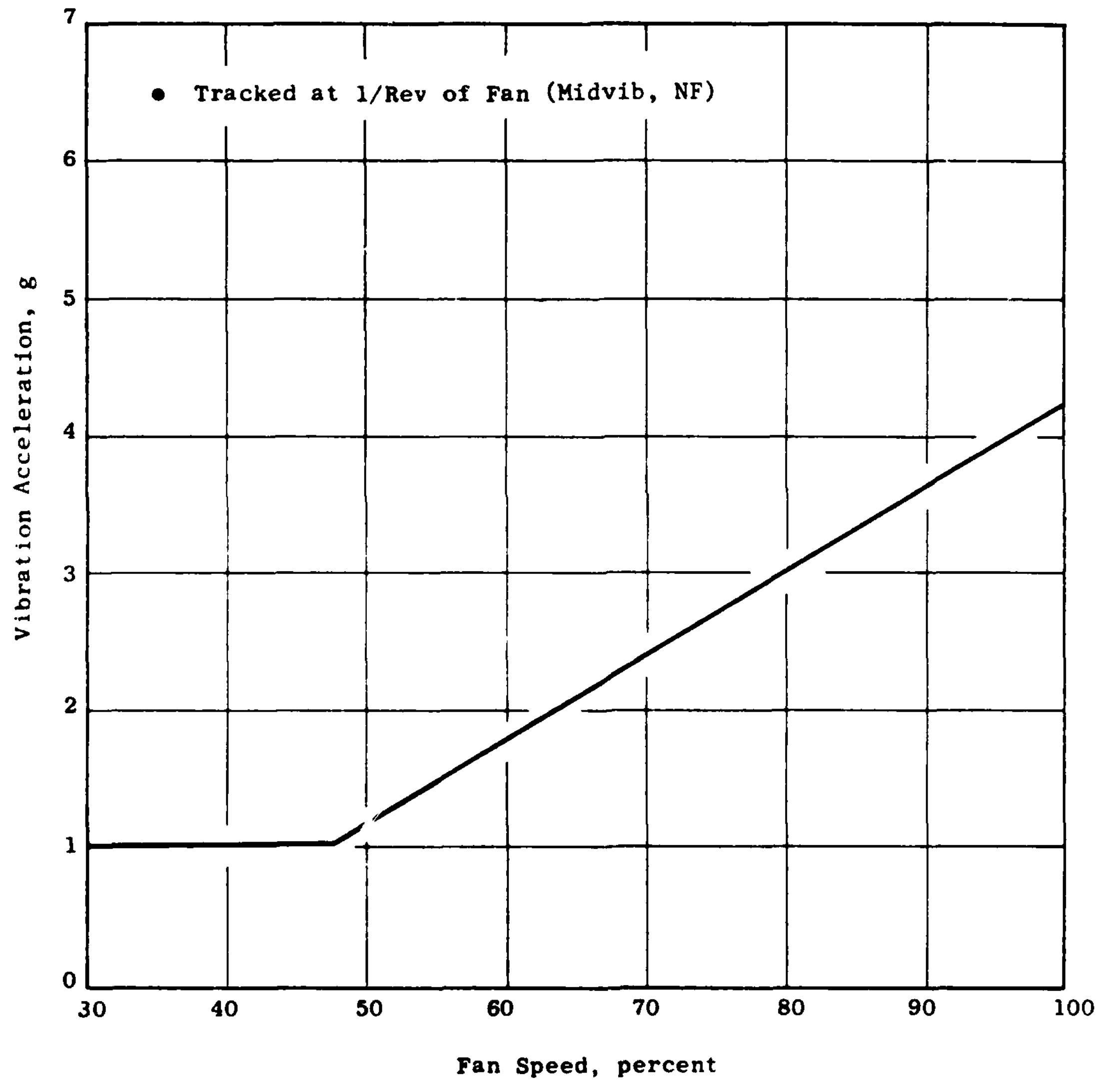


Figure 5. Midfan Vibration Versus Fan Speed.

Table 4. CITS Trending Data Requirements.

NF	Fan Speed
NC	Core Speed
AFF	Airframe Fuel Flow
CFF	Core Fuel Flow
T4B	Engine - Temperature
FGC	Calculated Thrust
PT2	Engine Inlet Pressure
T2	Fan Inlet Temperature
PT25	Fan Discharge Pressure
PS3	Compressor Discharge Pressure
A8 (EIS)	Nozzle Area (Engine Instruments)
DP/P	Fan Duct Pressure Ratio
BF	Inlet Guide Vane Angle
FWDVIB	Forward Vibration
FWDFVIB	Forward Fan Vibration
MIDVIB	Midvibration
MIDFVIB	Midfan Vibration
MIDCVIB	Midcore Vibration
AFTVIB	Aft Vibration
PL	Lube Pressure
TL	Lube Temperature
QL	Lube Quantity
AISP	Anti-ice Switch Position
PLA	Power Lever Angle
MO	Mach Number
PS	Static Pressure
CWA	Check Word A
A8TM	Nozzle Actuator Torque Motor Current
MTM	Main Torque Motor Current
WFRTM	Augmentor Fuel Valve Torque Motor Current
BFTM	Fan IGV Torque Motor Current
A8	Nozzle Actuator Position (CITS Processor)
PAUGSW	Augmentor Permission Signal
FDS	Flame Detector Signal
PWFR	Augmentor Fuel Pressure
WFR/PS3	Augmentor Fuel Valve Position
TF	Engine Fuel Inlet Temp
FFLT	CITS Flight/Ground Discrete
LE	ETCS Loop Error Signal
TCL	ETCB Thrust Control Lever Position
REF	ETCS Control Reference Voltage
TFAT	Free Air Stream Temp
S/N	Engine Serial Number
AICD	Anti-ice Command
A/C #	Aircraft Number
POS	Position
DATE	Date
TIME	Time
FLIGHT	Flight
QL/T	Lube Consumption (1)

(1) Calculated rate based on oil added between flights by maintenance.

1. Time, Core Speed, Fan Speed, and Engine Temperature

Record time, NC (core speed), NF (fan speed), and T_{4B} (engine temperature) simultaneously as long as one of the following three conditions exists:

- Fan overspeed
- Core overspeed
- Engine overtemperature

2. Low Cycle Fatigue

Record low cycle fatigue bit settings for the following measurements:

- NC (engine start)
- NF (fan speed)
- T_{4B} (engine temperature)
- PLA (idle-intermediate-idle)

3. Rapid Power Loss

When either constant or increasing power lever angle in conjunction with decreasing core speed is evidenced, record the parameters in Table 4 for the engine experiencing this phenomenon, taking readings at a rate of four times per second for 5 seconds.

4. Engine Trend Recording Requirements

The CITS records the parameters specified in Table 4, eight data "slices" or records in 2 seconds, for each engine which has met the preconditions for each of the following flight modes:

- Takeoff
- Climb
- Subsonic Cruise
- Supersonic Cruise
- Postflight - 90% NF Stablized Trend Point

At the end of each flight, each engine that has met the preconditions defined in the logic diagrams should have a total of 40 slices of data collected for ground processing trend analyses.

5. <u>Engine Fault and/or Fault Isolation</u>

The CITS records one data slice of all the parameters used in the engine test for all engines each time a fault is detected by the engine test. In addition to this data record, the fault name and work unit code for the LRU isolated by the test are also recorded. The recording of the time, engine position, fault name, and work unit code is also printed on the paper tape printer so that it will be readily available to the ground crew upon landing.

K. CITS TEST APPROACH

CITS testing is divided into on-ground and in-flight tests. In both cases, performance monitoring (to meet fault detection requirements), and fault isolation are performed.

The air vehicle CITS will provide testing for the engines in four different modes:

1. In-flight performance determination
2. Ground performance (or readiness) test
3. In-flight fault isolation to an LRU
4. Ground fault isolation to the same level

The mode selection only affects the output detail that the FTE (operator) receives via the CCD: it does not affect the actual engine test that is performed. The engine test senses the proper mode, either on the ground or flying, and automatically performs only the appropriate sections of the test logic.

If a failure occurs in the CITS system, this failure will not cause a failure or degration in the engine subsystem or in any subsystem which interfaces with the test system.

L. FAULT AND ISOLATION MESSAGES

CITS isolated LRU's are defined in Table 5; fault messages are defined in Table 6.

M. TEST LOGIC DIAGRAM GROUND RULES

The engine test logic diagrams have been prepared in accordance with the following set of ground rules:

Table 5. CITS Isolated LRU's.

Nomenclature	Abbreviation
IGV servovalve/actuator	---
Main fuel pump	MFP
Basic engine	BE
Main fuel control	MFC
Alternator	ALT
CITS processor	CITSP
Augmentor fan temperature control	AFTC
Fan inlet temperature sensor	FITS
Fan speed sensor	---
A8 hydraulic pump	ASHP
Augmentor fuel control	AFCTL
Lube scavenge pump	LSP
Main fuel control/aft control	MFC/AFTC
Aft control/basic engine	AFTC/BE
Main fuel control/basic engine	MFC/BE
Aft control/augmentor fuel control	AFTC/AFCTL
Augmentor fuel pump/augmentor fuel control	AFP/AFCTL
Main fuel control/augmentor fuel pump	MFC/AFP
Augmentor fuel control/basic engine	AFCTL/BE
Augmentor fuel pump/basic engine	AFP/BE
A8 hydraulic pump/basic engine	A8HP/BE
Compressor inlet temp sensor/main fuel control	T25/MFC
AFTC/pyrometer/basic engine	AFTC/T4B/BE
Pyrometer/AFTC/basic engine	T4B/AFTC/BE
MFC/AFCTL/augmentor fuel pump	MFC/AFCTL/AFP
T5 Probe	T5
Augmentor ignitor/exciter/flame detector	AUGIGN/EXC/FDS

Table 6. Engine CITS Messages.

Alphanumeric Messages

ENG n	ENG n COMPR STALL
ENG n RPM HI	ENG n VIB HI
ENG n T4B HI	ENG n UNSTAB
ENG n SIG FAULT	ENG n A8 OFF SCHED
ENG n SLOW TO 15 PCT	ENG n WFAB OFF SCHED
ENG n LUB PRESS LOW	ENG n IGV OFF SCHED
ENG n LUB TEMP HI	ENG n LOW THR
ENG n LUB QTY LOW	ENG n NO AUG
ENG n HOT START	ENG n START/NO LITE
ENG n LO PWR LOSS	ENG n SLOW/NO START

1. Reenter test logic sequence after each output if subsequent tests are unaffected.

2. Display each output on CITS control and display unit (CCD) for a gross indication of unacceptable subsystem performance. (The engines are a subsystem in this context.)

3. Display supplementary information for each output on CCD alphanumeric message board. (For example, engine position and fault detected.)

4. Print all alphanumeric messages and isolations work unit codes (WUC) on the CITS printer, along with time at which failure occurred (Tables 6 and 7).

5. Record all alphanumeric messages and failure data slices on the CITS digital recorder, along with the time at which failure condition occurred.

6. Failure isolation test routines are automatic and results may be requested both in-flight and on the ground, unless otherwise specified.

7 Logic diagram symbols are defined as shown in Figure 6.

8. The preconditions for the test shall be indicated on the test logic diagrams adjacent to the "Enter" function. A precondition is any condition which impacts the test logic sequence or content.

9 Unless otherwise noted, the outputs to the crew will only occur upon the third consecutive evidence of that condition monitored by CITS.

10. The displays associated with an output follow a format which is shown next to the input/output parallelogram symbol.

A complete set of the engine test algorithms can be found in the following Rockwell International Documents:

1. Interface Control Document, B-1 Air Vehicle/F101-GE-100 Engine Turbofan, Augmented (U), No. NA-69-929A, Section 90.0 - Appendix IX.

2. CITS Test Requirement Analysis for the Integrated Propulsion Subsystem, No. NA-73-255-8, Revised 11 June 1979.

The algorithms or logic found in Reference 1 apply only to the YF101 engines and are repeated, in a slightly different format, in Section IV of Reference 2. An interim set of algorithms used for initial flight testing the F101 engines in A/C 2 is found in Section 5.0 of Reference 2. The "latest" algorithms for any mix of YF101 and F101 engines can be found in Section 6.0 of Reference 2.

Table 7. Cross Reference of Work Unit Codes.

Printer Tape Codes E1	E2	E3	E4	Logic Diagram Codes	Abbreviations (See Table 5)	Recorder Codes
23256	23288	23320	23352	23HBC	MFP	-23HBC
23257	23289	23321	23353	23H**	BE	-23H**
23258	23290	23322	23354	23HAT	IGU SU/ACT	-23HAT
23259	23291	23323	23355	23HGB	MFC	-23HGB
23260	23292	23324	23356	23HGQ	ALT	-23HGQ
23261	23293	23325	23357	23HGW	CITSP	-23HGW
23262	23294	23326	23358	23HGX	AFTC	-23HGX
23263	23295	23327	23359	23HAA	FINTS	-23HAA
23264	23296	23328	23360	23HAB	NF SEN	-23HAB
23265	23297	23329	23361	23HGN	A8HP	-23HGN
23266	23298	23330	23362	23HGG	AFCTL	-23HGG
23267	23299	23331	23363	23HGL	LSP	-23HGL
23268	23300	23332	23364	(23HGB/23HGX)	MFC/AFTC	*23HGB
23269	23301	23333	23365	(23HGX/23H**)	AFTC/BE	*23HGX
23270	23302	23334	23366	(23HGB/23H**)	MFC/BE	*23HGB
23271	23303	23335	23367	(23HGX/23HGG)	AFTC/AFCTL	*23HGX
23272	23304	23336	23368	(23HGH/23HGG)	AFP/AFCTL	*23HGH
23273	23305	23337	23369	(23HGB/23HGH)	MFC/AFP	*23HGB
23274	23306	23338	23370	(23HGG/23H**)	AFCTL/BE	*23HGG
23275	23307	23339	23371	(23HGH/23H**)	AFP/BE	*23HGH
23276	23308	23340	23372	(23HGN/23H**)	A8HP/BE	*23HGN
23277	23309	23341	23373	(23HGF/23HGB)	T25/MFC	*23HGF
23278	23310	23342	23374	(23HGX/23HET/23H**)	AFTC/T4B/BE	*23HGX
23279	23311	23343	23375	(23HET/23HGX/23H**)	T4B/AFTC/BE	*23HET
23280	23312	23344	23376	(23HGB/23HGG/23HGH)	MFC/AFCTL/AFP	*23HGB
23281	23313	23345	23377	23HHP	T5	-23HHP

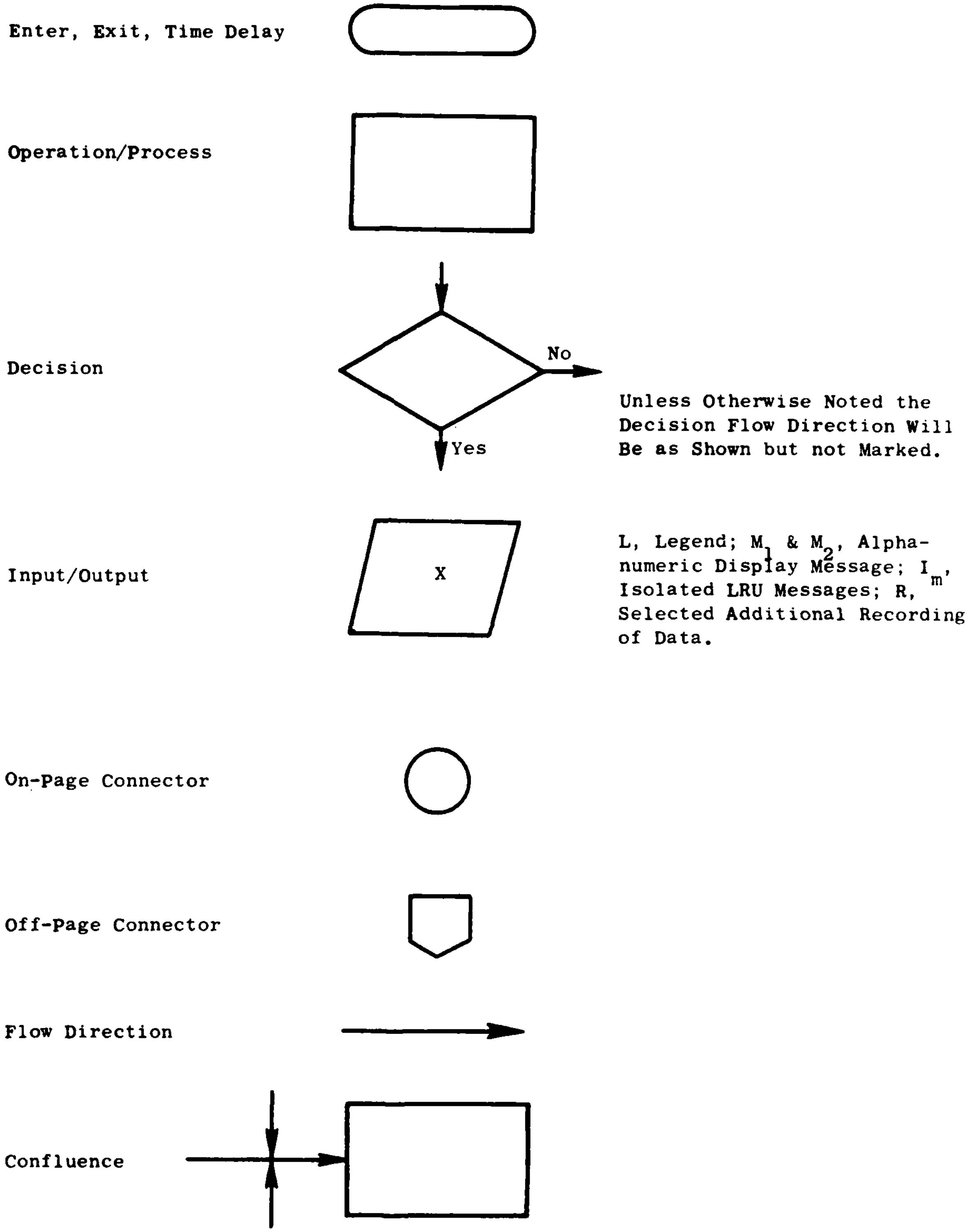


Figure 6. Test Logic Diagram Symbols.

The use of these "latest" algorithms began with Flight 4-12, and they will not be introduced to earlier air vehicles. Excerpts from Reference 1 and 2 will be included in numerous places herein.

SECTION III

RESPONSE TO MISSION POWER

The reason for analyzing the mission power loss events in the flight test program dates back to 1972 when agreement was reached between the USAF, Rockwell International, and General Electric as to the types of event that would be considered "faults" in measuring the CITS commitments for the program. At that time, it was agreed that a fault event would be defined as an event causing a "Mission Power Loss." A mission power loss (MPL) was, in turn, defined as a condition which kept the engine from delivering 90% or more of the normally available thrust for any given set of conditions. With these definitions finalized, it was then possible to measure against the contract the requirements that 95% of all engine faults be detected by CITS and 75% of these cases be isolated to the correct line replacement unit (LRU).

A. ANALYSIS OF CITS RESPONSE TO ACTUAL MISSION POWER LOSSES

At this writing, there have been 2[illegible] mission power losses (MPL) identified during the course of the B-1 Flight Test Program. Table 8 lists faults (MPL) identified during the B-1 Flight Test Program and CITS response to these faults in regard to accuracy of detection and isolation. A summary of this tabulation is compared to CITS goals and is followed by individual discussions of the fault cases.

For scoring purposes, those responses which would have been correct using current CITS software will be scored as correct even though detection and/or isolation was incorrect at the time of the event. In cases where multiple isolations or maintenance actions are specified, if one is correct, the case is scored as a correct isolation.

Faults are classified as mature and immature. CITS was designed to identify mature faults - that is, faults that would be expected to occur even in a mature engine, i.e., with 500,000 accumulated engine flight hours. Several faults occurred in the B-1 Flight Test Program that would be classified as

Table 8. CITS Detection and Isolation of B-1 Mission Power Losses.

Case No.	Fault Class Mat.	Fault Class Imm.	Fault	Detection Correct	Detection None or Incorrect	Not Program	Isolation Correct	Isolation None or Incorrect
1	X		No. 4 Brg. Failure	X			X	
2		X	Hot Start Assembly Error	X			X	
3	X		HP Rotor 83% Speed	X				X
4		X	Aug. Instab. - Screech	X			X	
5		X	Aug. Instab. - Screech	X			X	
6		X	Lube System - Gulping	X				X
7	X		No Aug. Light - Exciter	X			X	
8		X	No Aug. Light - MEC	X				X
9	X		Hot Start - Bleed Bias Line	X				X
10	X		No Aug. Light - Exciter	X			X	
11		X	Aug. Pump Fuel Leak		X	X		X
12		X	FDT Sensor Contamination	X				X
13	X		No Aug. Light - Ignitor	X			X	
14		X	Aug. Pump - Lube Leak	X				X
15		X	Aug. Pump Fuel Leak		X	X		X
16		X	Aug. Pump Fuel Leak		X	X		X
17		X	Lube System Gulping	X				X

X Mature Fault Case

Table 8. CITS Detection and Isolation of B-1 Mission Power Losses (Concluded).

Case No.	Fault Class		Fault	Detection		Not Program	Isolation	
	Mat.	Imm.		Correct	None or Incorrect		Correct	None or Incorrect
18	X		No Aug. Light - Ignitor	X			X	
19	X		No Start - Deterioration	X			X	
20	X		No Aug. Light - Ignitor	X			X	
21		X	Lube System Gulping	X				X
22		X	Lube System Gulping	X				X
23		X	Lube System Gulping	X				X
24		X	Lube System Gulping	X				X
25	X		T_2 Sensor Cold Shift	X				
26	X		No Aug. Light - Ignitor	X			X	
27	X		No Aug. Light - Ignitor	X			X	
28	X		No Aug. Light - Ignitor	X			X	
29	X		Unscheduled Shutdown	X				X
TOTALS	14	15		26	3	3	13	16

X Mature Fault Case

immature faults - faults that, having been identified, have been designed out of the F101 system and either would not occur or would be unlikely to occur in the mature engine. Failure to detect immature faults is not charged against the CITS system effectiveness for purposes of this report; although in many cases, immature faults were detected or would have been detected by the mature CITS software program. It is not unusual for the aircraft CITS to be off-line for significant intervals one or more times during a flight or ground run, the causes ranging from intentionally being turned off to priority assignment of the computer. A/C 3 and 4 use an envelometer which schedules on-line operation of the CITS to conserve recording tape. Significant events are often missed simply because the CITS is off-line during the event. The CITS paper tape printer is usually operational during these periods if powered; however, no CITS parameter data are recorded. Scoring of CITS effectiveness assumes that the aircraft CITS would be on-line in an operational environment.

Detection:

- Of 14 mature faults, all were detected (100%).
- Of 15 immature faults, 12 were detected (80%).

These values may be compared to the CITS requirement value of 95% detection of mature faults.

Isolation:

- Of the 14 mature fault cases, 10 were isolated correctly (71.4%).
- Of the 15 immature fault cases only three were isolated correctly (20%).
- Overall correct isolation (13 of 29) was 44.8%.

The CITS requirement for correct isolation of mature faults is 75%.

B. MISSION POWER LOSS EVENTS

Case No. 25 represents a classic event of fault detection and isolation of a mature fault. This cause is presented first for a comprehensive examination. CITS was fully operational at the time of the event, and recorded

CITS data were available as well as full flight test recorded data for the same time period. A comparison of data is presented for the purpose of showing CITS data repeatability in relation to data values recorded from normal flight test instrumentation.

1. FDT Sensor Cold Shift (One Event)

Case No. 25:

Statistics: Flight 2-54: Engine Position 2: Engine S/N 470-082

Case: The FDT sensor bulb charge pressure was lost causing the compressor stator vanes to track off-schedule in the open direction.

Fault Class: Mature

Detection

The initial detection for this fault was "2057 23289 Eng 2" (Figure 7). This fault was NC versus NF out-of-limits at 2057 hours. The "23289" is the work unit code (WUC) for the basic engine as the LRU. Logic for this detection is shown on Figure 8. When data obtained from the CITS failure data "snapshot" are plotted on the software limits curve NCK versus NFK, they show the out-of-limits condition (Figure 9). At 2124 hours, speed ratio was flagged again (Figures 9 and 10).

A third detection was made at 2153 hours: "2153 23291 Eng 2" (Figure 11). This fault may be identified as Low PS3 and the WUC specifies the LRU as the main engine control. Logic is shown in Figure 12, and a plot of four samples/second data from the flight test data system is presented on Figure 13.

At 2155 hours "Eng 2 Low Pwr Loss" was detected (Figure 11). The logic diagram for this fault is shown on Figure 14. Switch 5 (SW5) is set to zero during the start sequence at 62% NC and is not reset to "1" until a start sequence on that engine is again initiated. Following the "Low Pwr Loss" detection, the engine is bypassed for further CITS checks until an engine restart is initiated. Thus, "T_{4B} Hi," "Low P_{S3}," and "Engine Stall"

2-54

DATE: 11/23/73 CITS PRINTER DATA Sht 5 of 9

MESSAGE				
1828 41148 R WSHLD HOT	1828 SPOIL	1828 14553 SPOIL	1828 46050 FUEL	1828 46057 FUEL
1829 CREW ESC MAIN CHUTE	1829 16006 CREW ESC MAIN CHUTE	1832 41160 SPD BK SYMM 1	1905 ENG4 WFAB OFF SCHED	
1905 ENG1 WFAB OFF SCHED	1905 23362 ENG4	1905 23266 ENG1	1905 ENG3 WFAB OFF SCHED	1905 23330 ENG3
1905 ENG2 WFAB OFF SCHED	1905 23298 ENG2	1905 ICE DETR R	1905 23453 ICE DETR R	1905 46058 FUEL
1943 46012 FUEL	2006 41048 ECS	2034 14204 WING SWP	2057 23289 ENG2	2057 41209 ADC 2

FORM 2000-D-180 NEW 3-76 (PAGE 2)

Figure 7. CITS Printer Data.

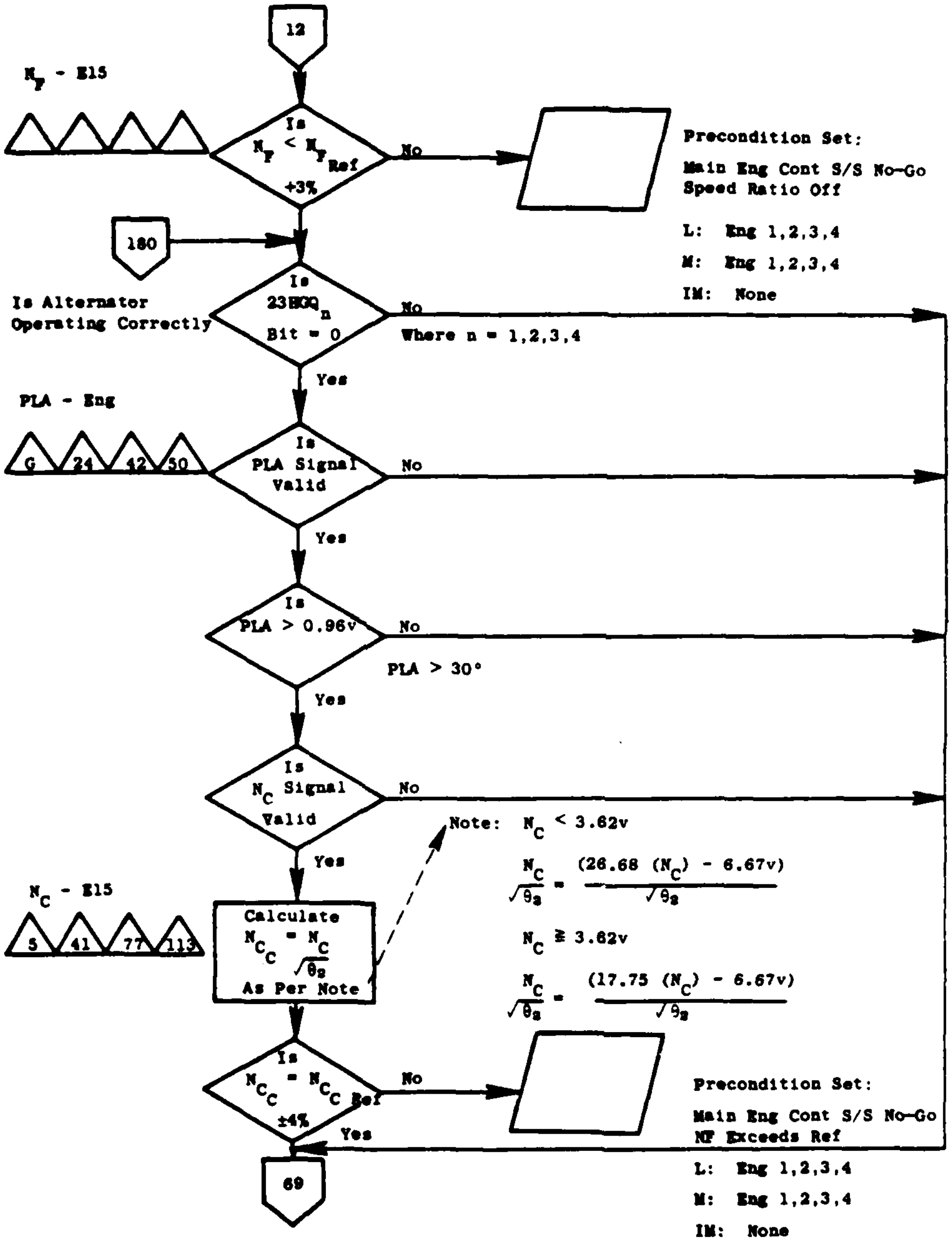


Figure 8. Speed Ratio Check Logic.

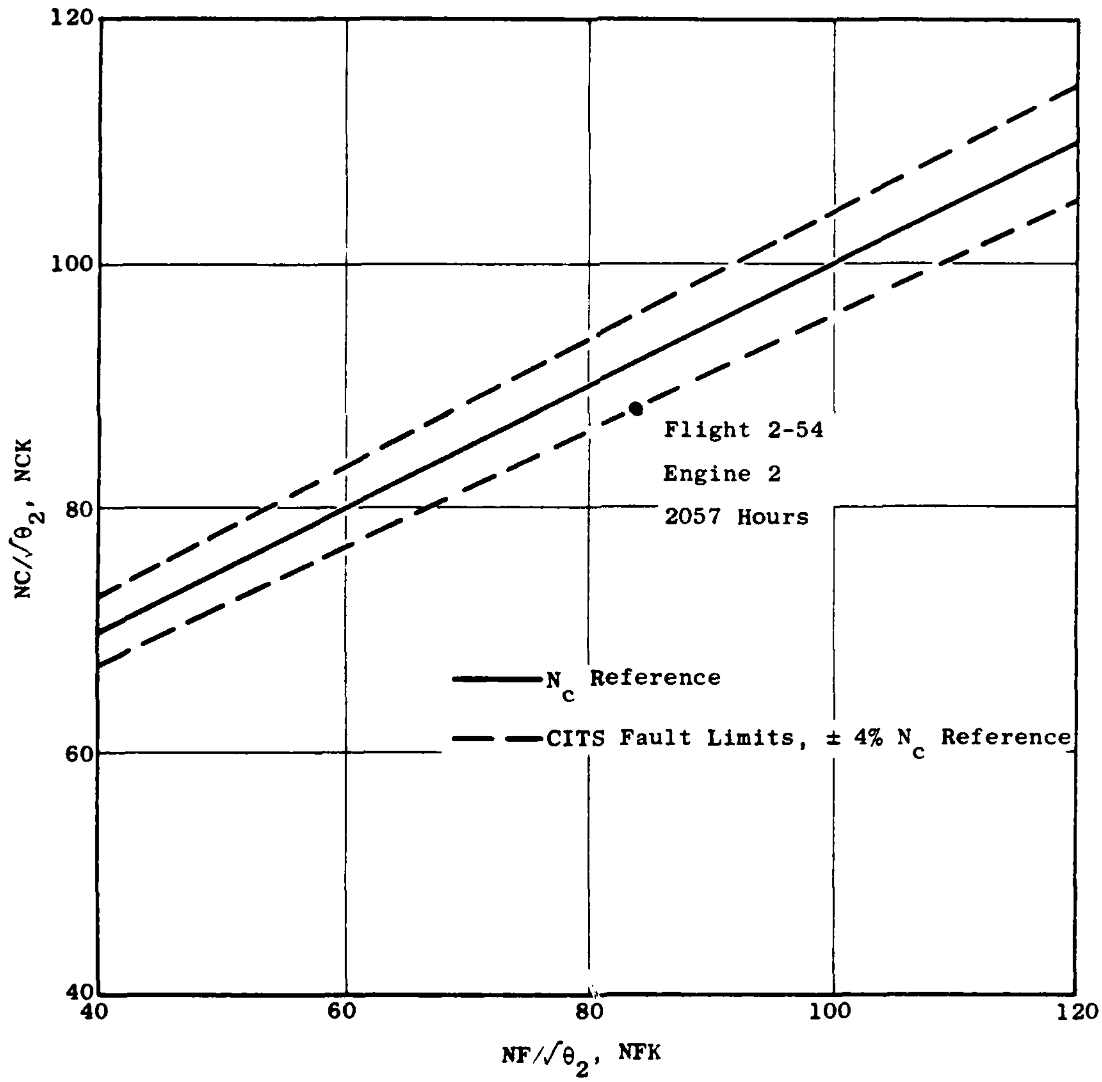


Figure 9. Corrected Fan Speed Versus Corrected Core Speed (NC_{Cref}).

2-54

CITS PRINTER DATA

DATE: 11/28/79 Sht 7 of 9

MESSAGE

2116 23124 AICS1 2118 46050 FUEL 2118 CITS PTR 2118 55005 CITS PTR 2118 ENG2 SIG FAULT

2118 23293 ENG2 2120 WING SWP 2120 14202 WING SWP 2120 ENG2 THROT 2120 ENG2 THROT AUTO

2120 23418 ENG2 THROT 2120 ENG4 THROT 2120 ENG4 THROT AUTO 2120 23422 ENG4 THROT 2121 41038 ECS

BE

2121 SCAS 2121 14077 SCAS 2124 ENG2 2124 23269 ENG2 2125 ENG4 2125 ENG4 SIG FAULT

2125 23357 ENG4 2125 ENG4 AB OFF SCHED 2125 ENG3 2125 ENG3 AB OFF SCHED 2125 ENG1

FORM 2000-B-160 NEW 3-76 (PAGE 2)

Figure 10. CITS Printer Data.

2-5-4

DATE: 11/28/78

CITS PRINTER DATA

Sht 8 of 9

MESSAGE

2125 ENG1 AB OFF SCHED 2125 ENG2 AB OFF SCHED 2125 23356 ENG4 2125 23326 ENG3 2125 23294 ENG2

2125 23262 ENG1 2127 AFCS 2127 14700 AFCS 2127 ENG3 SIG FAULT 2127 ENG1 SIG FAULT

2157 23142 AICS2 2213 41148 R WSHLD HOT 2215 41182 SPD BK SYMM 1 2216 23321 ENG3 2216 SCAS

2127 23325 ENG3 2127 23261 ENG1 2130 23119 AICS1 2132 23206 AICS4 2138 ICE DETR L

2138 23452 ICE DETR L 2138 41156 R WSHLD HOT 2153 23291 ENG2 2155 ENG2 LOW PWR LOSS

FORM 2000-D-160 NEW 3-76 (PAGE 2)

Figure 11. CITS Printer Data.

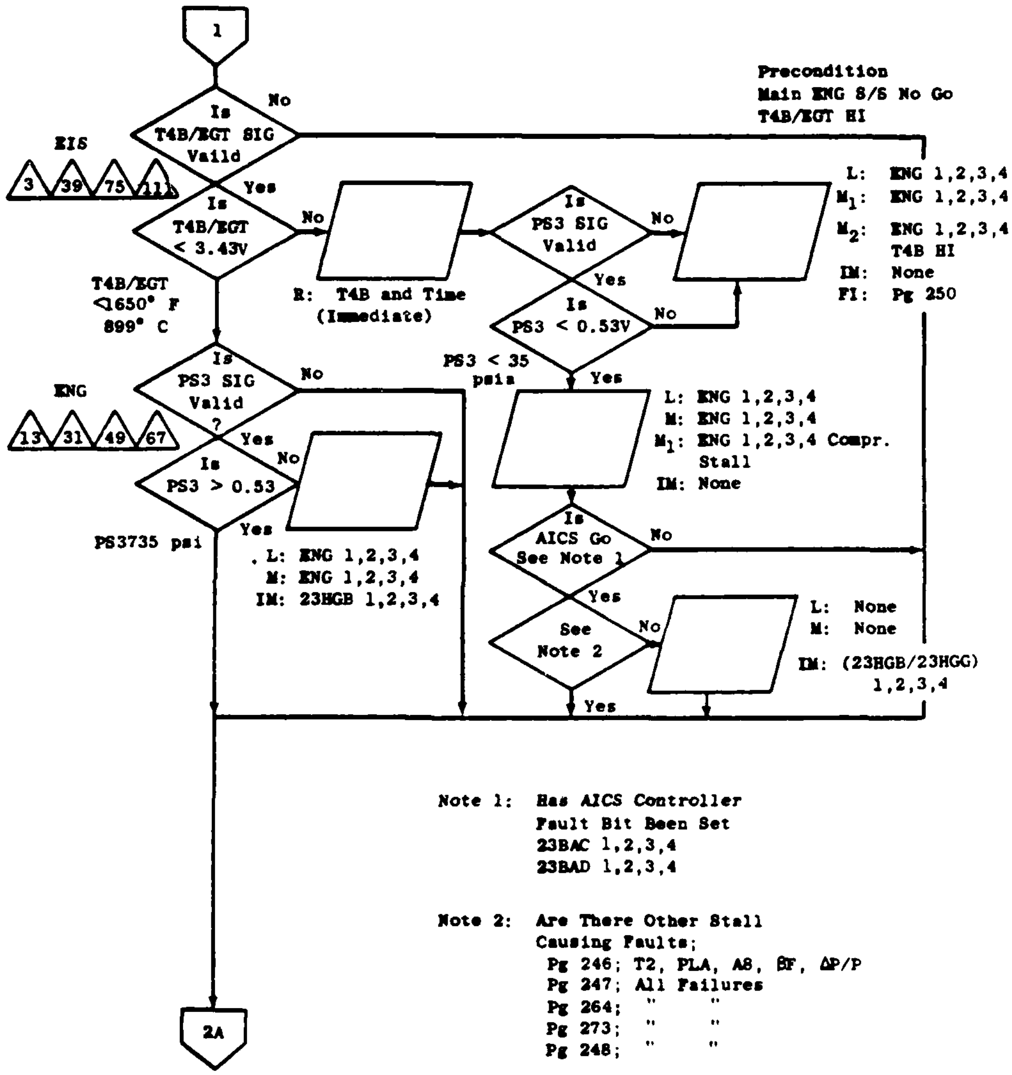


Figure 12. Stall Detection Logic.

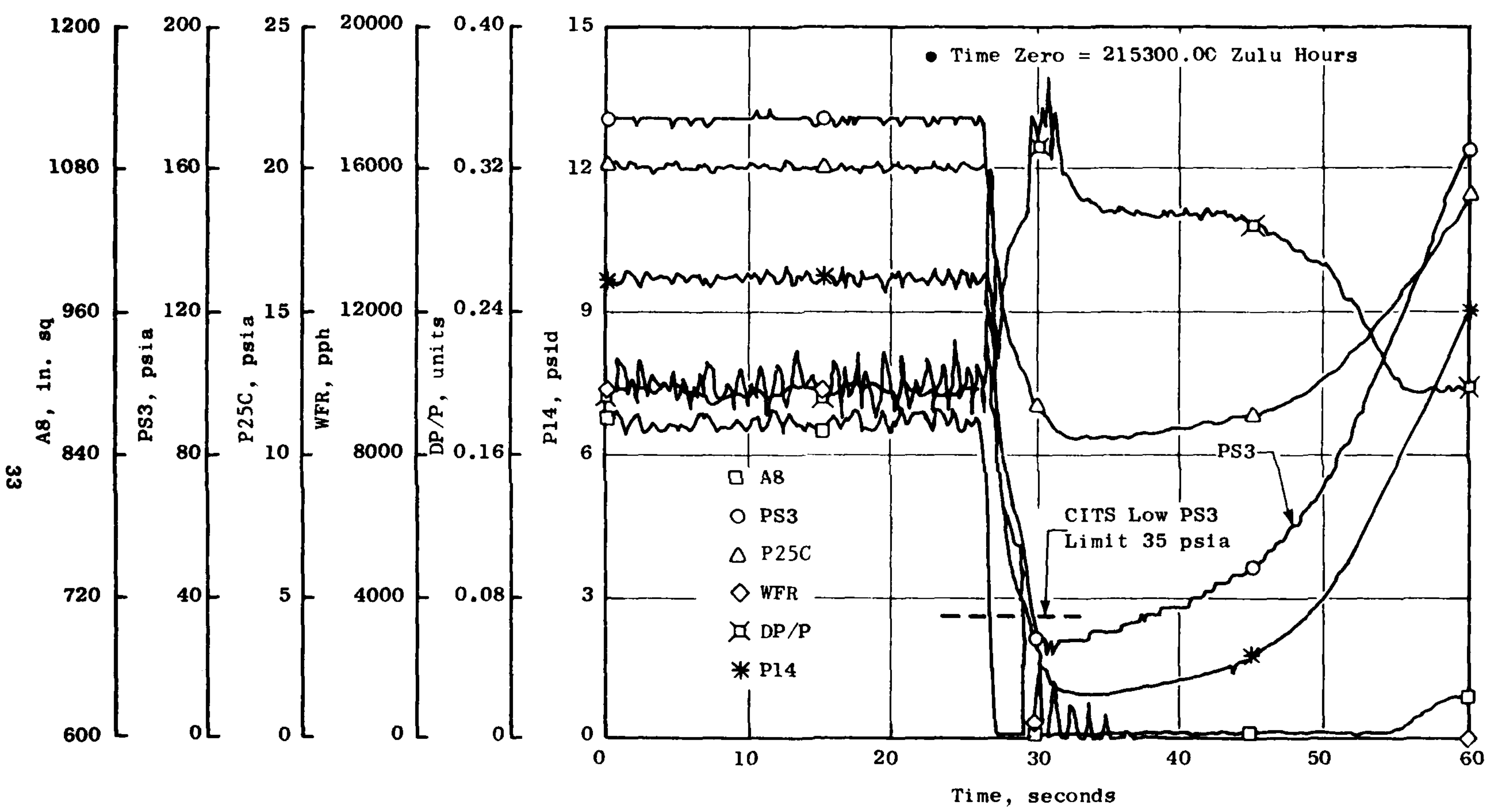


Figure 13. Flight 2-54 - Prior to Stall - Low P_{S3}.

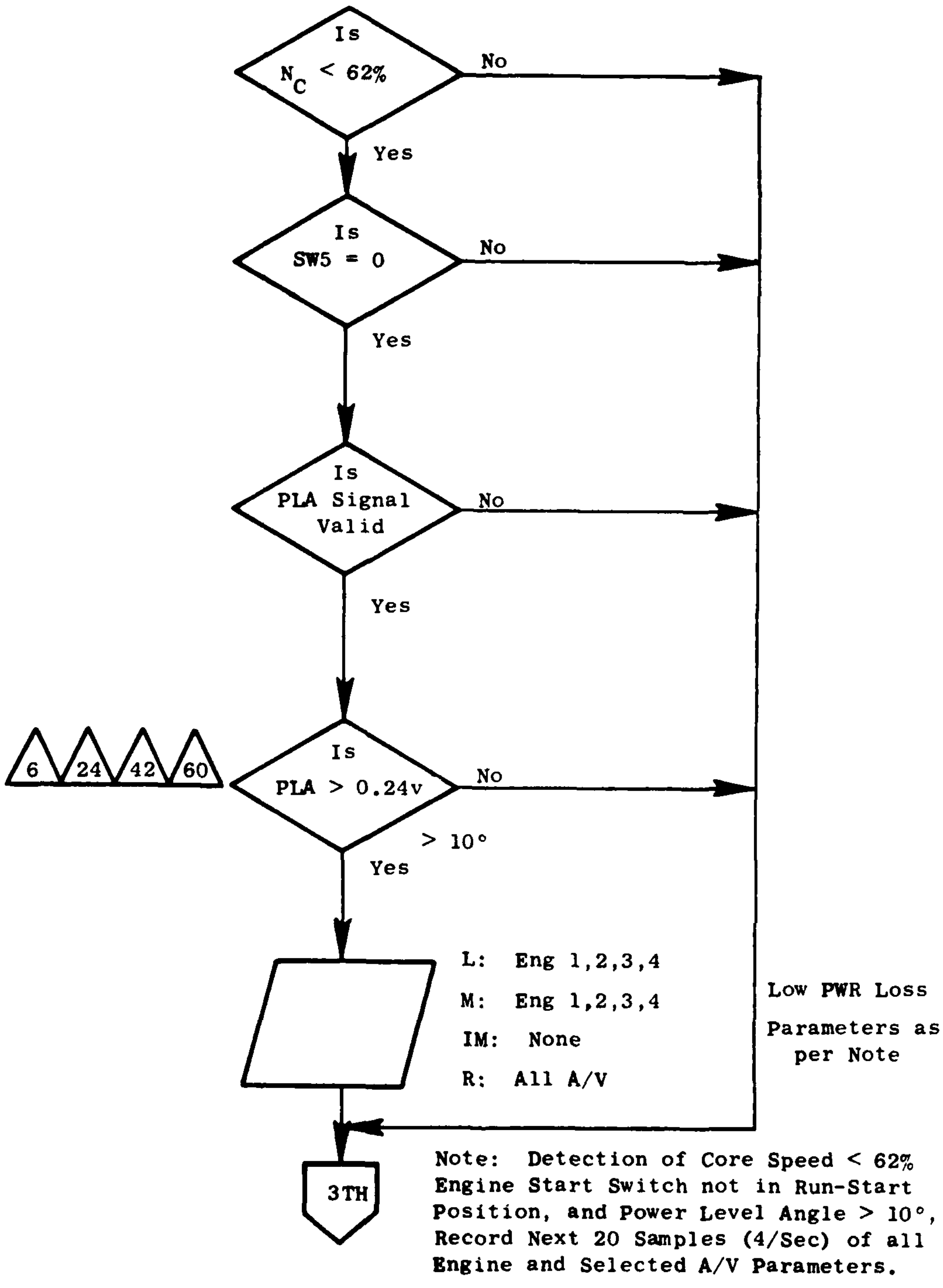


Figure 14. Low Power Loss Logic.

events following the "Low Pwr Loss" were missed (Figures 15 and 16). The critical parameters for the "Low Pwr Loss" are plotted on Figure 15. Figure 16 shows the three events that were missed.

Isolation

Isolation of the 2057 hours detection (NC versus NF out-of-limits) was made to WUC "23289" (Figure 7) which is the basic engine. This isolation is incorrect; the correct isolation would have been to the FDT sensor. Current logic does not isolate to an LRU for this fault, "IM:NONE" (Figure 8). The same isolation was made for the same fault at 2124 hours (Figure 10).

Isolation to work unit code "23291" (Figure 11), which is the main engine control, was made at the 2153 hours "Low PS3" detection. This isolation was also incorrect. Work unit codes (WUC) shown in the logic (Figure 12) "23H6B1, 2, 3, 4" are equivalent to "23291" for Engine 2. A cross reference for these semiverbal and numeric WUC's is shown in Table 7.

No isolation is programmed for the "Low Pwr Loss" fault detected at 2155 hours.

2. Plugged Lube Jet - No. 4 Bearing Failure - (One Event)

Case No. 1:

Statistics: Flight 1-12, Engine Position 2, Engine S/N 470-045

Cause: No. 4 bearing froze due to oil starvation; lube passage in casting plugged with core material; locked LP and HP rotor together; engine stalled.

Fault Class: Mature

Detection: This event was not detected due to aircraft CITS being off-line at the time. Had CITS been on-line, detection would have identified "vib high," then "eng. stall," and finally "T_{4B} high." A record showing 12 seconds of T_{4B} over 901° C limit would have been recorded (see Figure 17).

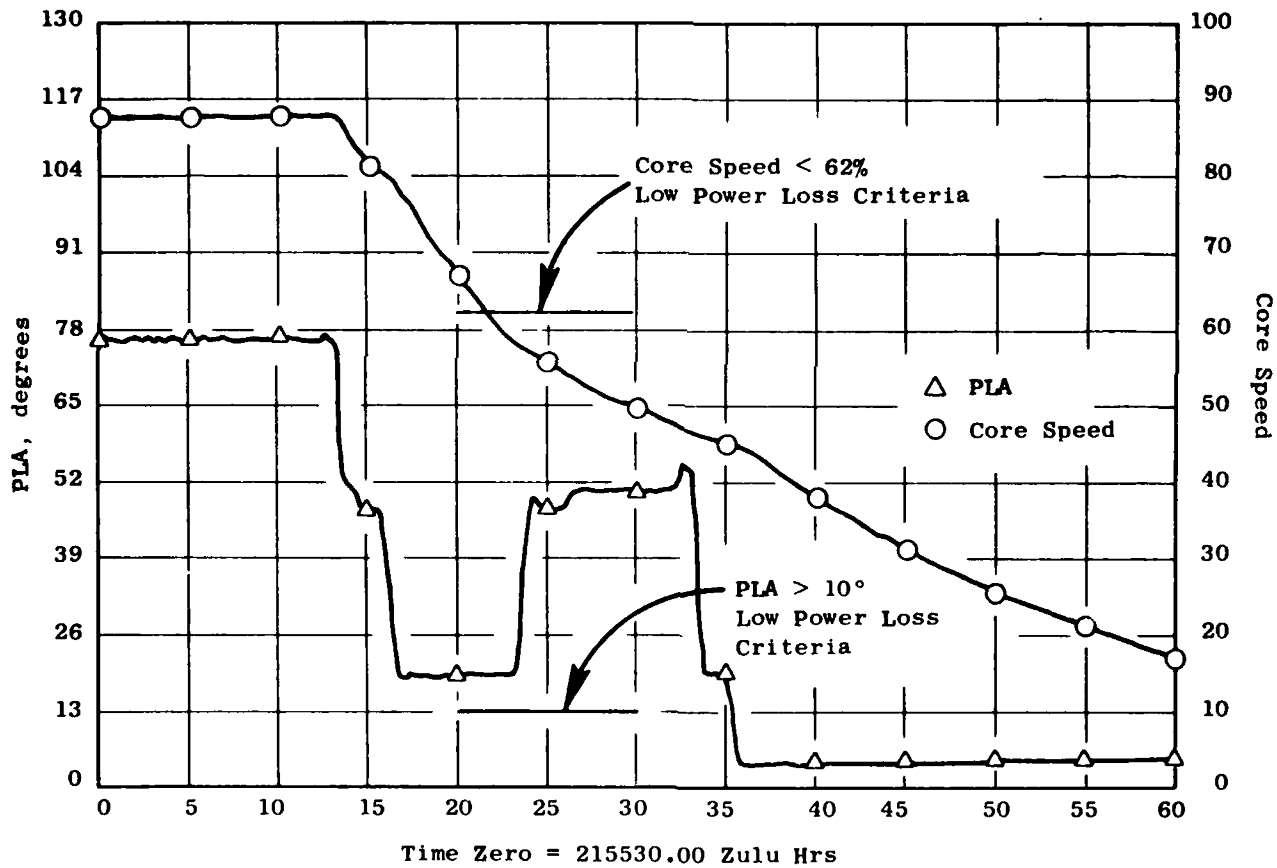
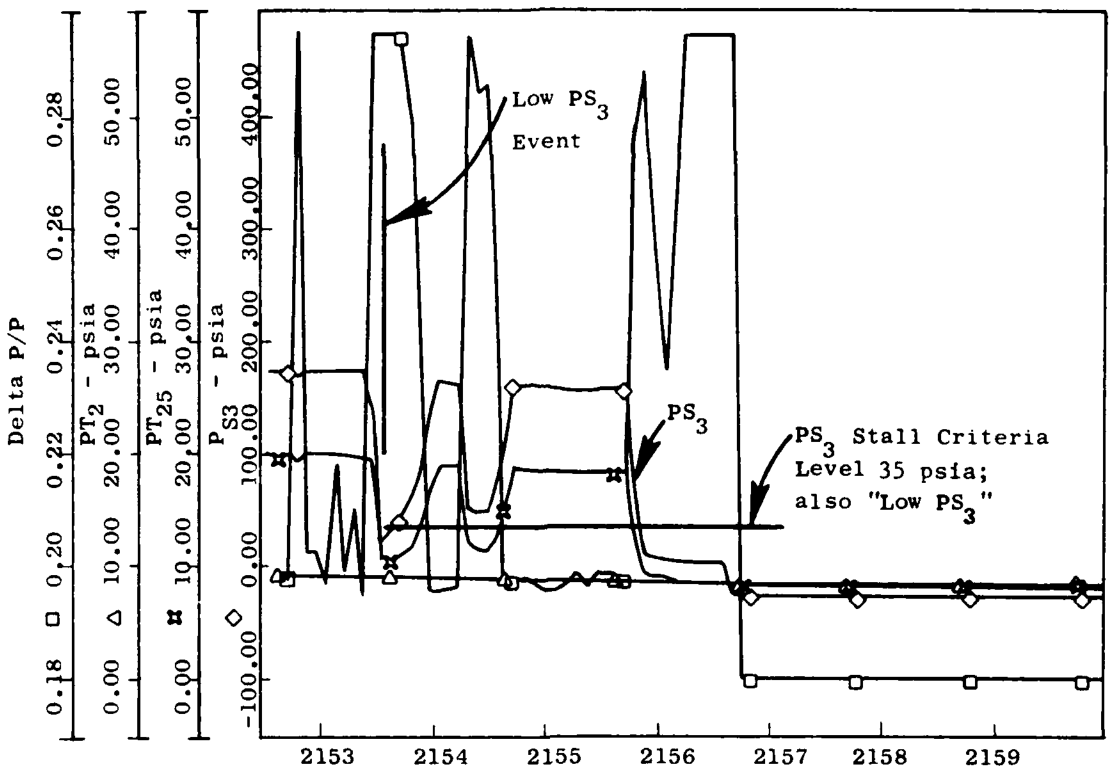


Figure 15. Flight 2-54, Stall - Low Power Loss.



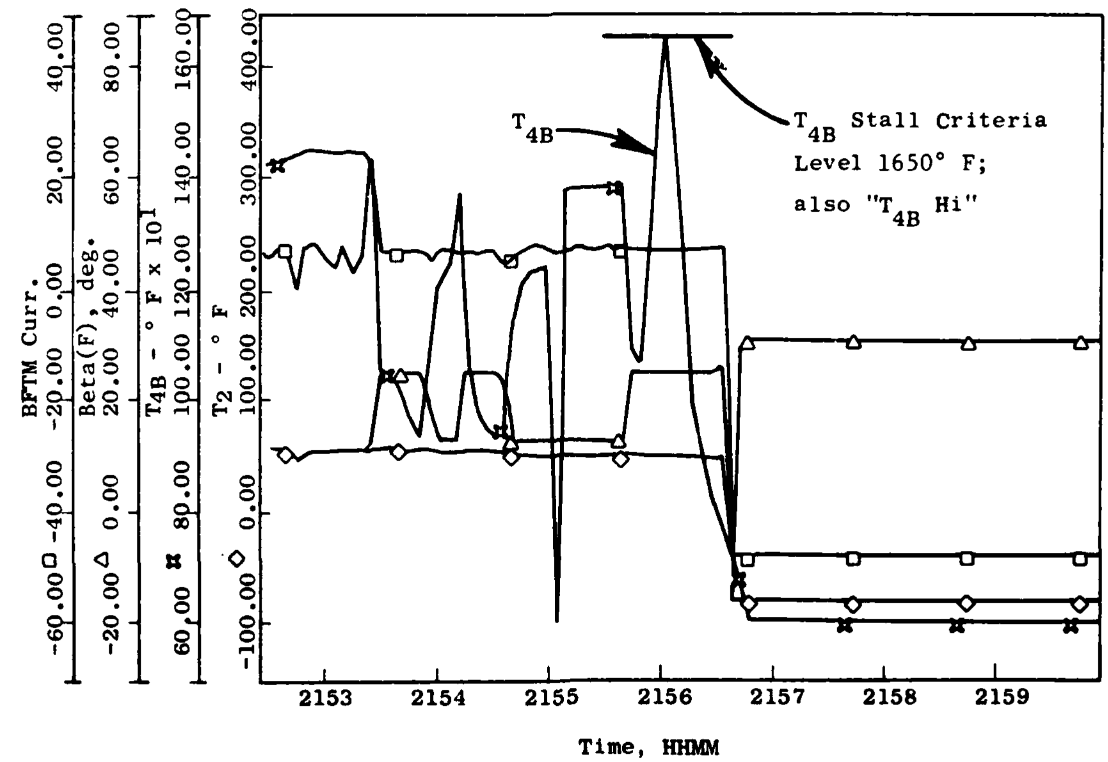


Figure 16. Flight 2-54 - Engine 2 Events - Low P_{S3}
T_{4B} High - CITS Parameters - 1 Sample/5 Seconds.

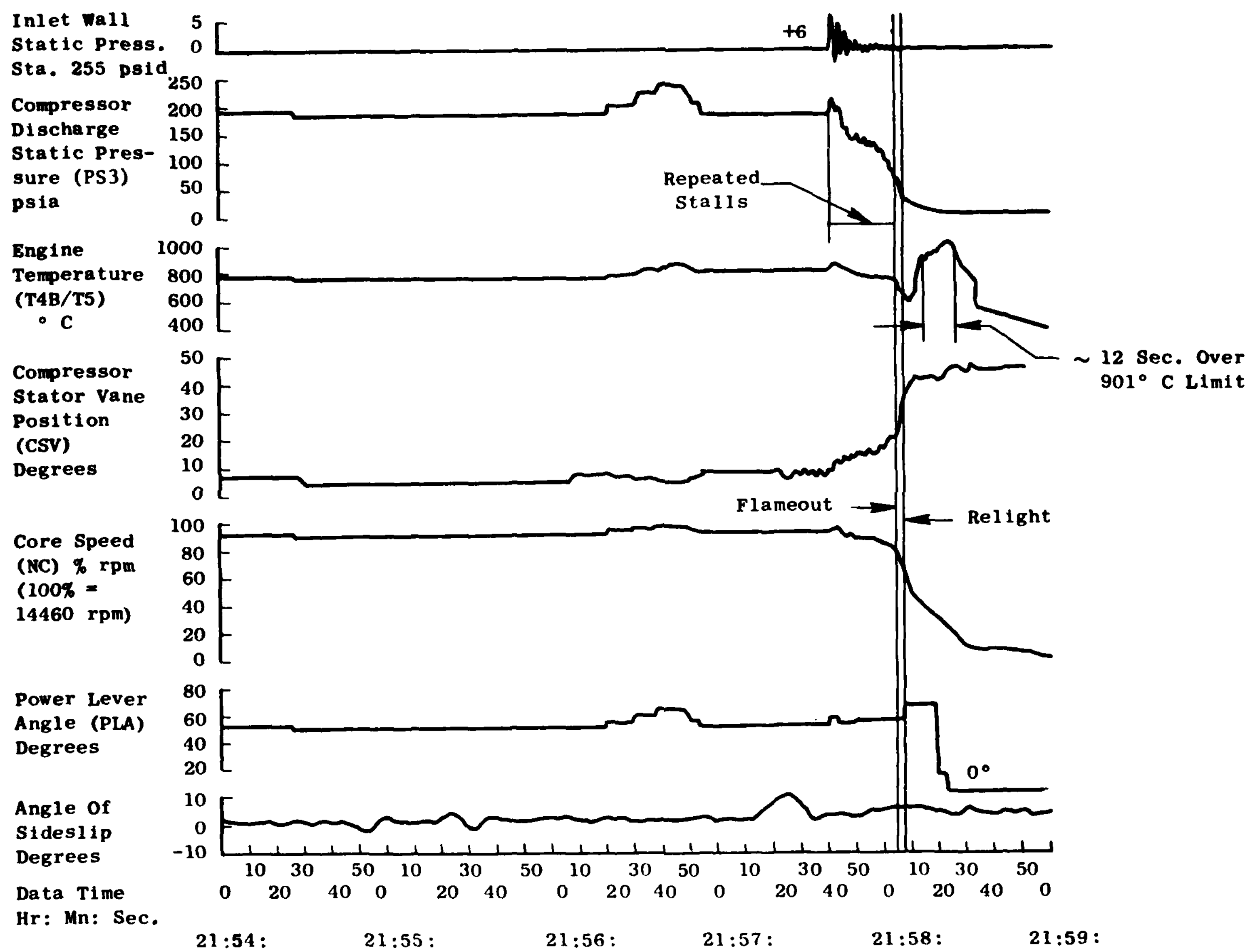


Figure 17. Stall Incidence - Engine 470-045 - Flight 1-12.

Isolation: Correct isolation to basic engine would have been indicated.

3. Hot Start - Assembly Error - (One Event)

Case No. 2:

Statistics: Ground Test - A/C 1, Engine Position 4, (10-3-75), S/N 470-044

Cause: Assembly error; bolts left out of CDP bleed ring; ring detached from rabbet, partially blocking flowpath, resulting in hot starts.

Fault Class: Immature

Detection: No data were recorded during this portion of the ground test. CITS would have detected "slow no start," then "T_{4B} High" or "Hot Start."

Isolation: Isolation would likely have been to "MFC."

4. HP Rotor Speed Limited to 83% AFTC Failure - (One Event)

Case No. 3:

Statistics: Flight 3-2; Engine Position 1; S/N 470-056

Cause: An open resistor was found in the voltage regulation section of the AFTC caused by built-in impurities. Vendor quality control procedures have eliminated this source of failure. No further faults of this nature have occurred.

Fault Class: Mature

Detection: CITS was inoperative at time of event. "Low Thrust" or "NC versus NF off schedule" would have been detected.

Isolation: Isolation would probably have been to the alternator since this fault characteristic is indicative of an electrical power failure. Use of additional existing parameters and software could provide proper isolation.

5. Augmentor Instability - (Two Events)

Cases No. 4 and 5:

Statistics: Flight 1-31; Engine Positions 3 and 4; S/N 470-052 and -048

Cause: Augmentor exhibited combustion instability at Mach 2.0 resulting in damage to exhaust nozzle.

Fault Class: Immature

Detection: CITS would have detected this event had not the system alarm been disarmed due to a previous "vib high" warning on this engine. False "vib high" warnings were common during this period of testing due to a system problem that has since been corrected.

A tab out of CITS parameter data (Figure 18) shows that the aft broadband vib level (VAB) of both engines (3 and 4) was 17.9 g's. Limit level is 12.5 g's on this parameter.

Isolation: CITS would have isolated correctly to the basic engine.

6. Low Lube Quantity - High Lube Temperature Lube System Discrepancy - Gulping (Six Events)

Cases No. 6, 17, 21, 22, 23, 24

Statistics:

Case No.	Flight No.	Engine Position	Engine S/N
6	3-18	3	470-059
17	1-68	3	470-082
21	2-47	3	470-086
22	2-51	4	470-085
23	2-52	4	470-085
24	2-54	3	470-086

FLT 1-31

CITS F101 ENGINE FLIGHT DATA

SUBSYSTEM - ENGS — TIME -- 23:27:26.24

	PLA	T2	NF	MTM	BFTM	A8	A8TM	DP/P	WFR/PS3	WFRTM	AUGSW	BETA(F)
ENG 1	127.6	600.0	92.9	19.4	7.4	9.21	10.8	0.335	264.5	14.2	212.0	1.2
ENG 2	120.1	690.0	92.9	21.3	5.1	0.13	16.0	0.341	263.1	10.0	212.0	1.2
ENG 3	1.5	373.3	-5.7	48.1	-48.1	-1.10	-40.1	0.205	38.3	-48.1	0.	1.5
ENG 4	129.7	692.7	92.9	17.6	7.4	9.42	13.0	0.341	264.5	17.5	213.0	1.2

	PWFR	P33	CWA	CWB	CWC	START	STOP	AISP	AICS	RESET	LOCKUP
ENG 1	1645.5	215.4	170.00	86.00	79.00	0.	0.	0.	0.	0.	1.0
ENG 2	1057.7	180.4	170.00	86.00	81.00	0.	0.	0.	0.	0.	1.0
ENG 3	-77.4	-25.5	0.	0.	0.	0.	0.	0.	0.	0.	1.0
ENG 4	1098.2	199.7	171.00	86.00	80.00	0.	0.	0.	0.	0.	1.0

MACH NO.	STATIC PRESS	CADVAL	IGN CONT.	IGN OFF
2.1	3.3	1.0	0.	0.

CITS F101 ENGINE FLIGHT DATA

SUBSYSTEM - ENIN — TIME -- 23:27:31.25

	NF	NC	T4B	A8	WFM	WFAUG	WFT	TF	PT25	PT2	PLVL
ENG 1	92.1	99.9	809.2	88.0	4540.1	45582.0	50122.1	83.3	27.0	17.2	8.7
ENG 2	91.0	99.0	895.4	61.1	4344.7	41734.5	46079.2	87.1	25.8	16.8	8.2
ENG 3	92.0	99.4	752.7	97.7	4317.6	45641.7	49959.3	80.2	27.1	17.3	9.3
ENG 4	91.4	99.7	893.1	89.1	4852.1	44049.0	48901.1	62.7	26.7	17.2	8.8

	QL	PL	TL	VFB	VFF	VMB	VMF	VMC	VAB	ETAL
ENG 1	52.35	36.5	221.4	1.6	0.7	1.9	0.7	1.0	1.3	0.
ENG 2	58.75	34.5	233.4	1.6	0.7	2.4	0.7	2.1	1.6	0.
ENG 3	42.80	39.8	226.4	1.4	0.5	8.0	0.0	1.0	17.9	0.
ENG 4	62.20	35.7	223.5	1.8	0.7	10.6	0.9	0.9	17.9	0.

LIMIT 12.5 g's

Figure 18. Augmentor Screech Damage.

Cause: This problem was identified as a lube system discrepancy which allowed oil to accumulate in the gearbox where it could not be properly scavenged. The problem was resolved by relocation of the air/oil separator. Proper operation of the lube system has been demonstrated, leading to the conclusion that this problem will not occur again.

Fault Class: Immature

Detection: Cases No. 6 and 17: CITS correctly detected "Lub Qty Low" then "Lub Temp Hi" (see Figures 19, 20, 21). Cases No. 21, 22, 23, 24: For these cases, special instrumentation had been added (lube scavenge temperature). Pilot recognized the approaching condition and avoided it prior to detection by CITS. CITS would have detected in all cases if condition had been allowed to develop.

Isolation: There is no isolation programmed for this event.

7. Augmentor Failed to Light

- Ignition Exciter (Two Events)
  Cases No. 7 and 10
- Main Engine Control (One Event)
  Case No. 8
- Augmentor Ignitor (Six Events)
  Cases No. 13, 18, 20, 26, 27, 28

Statistics/Fault Class

Case No.	Fault Class	Flight No.	Engine Position	Engine S/N
7	Mature	3-19	4	470-046
8	Immature	1-45	4	470-057
10	Mature	A/C 3 GT (3-25-77)	4	470-056
13	Mature	3-55	1	470-053

DATE: 9-16-76

CITS PRINTER DATA

Sht 10 of 10

MESSAGE

XECN1 TRANSPONDER 80000600 GT 20 36.15 721112 RECIR TRANSPONDER 00000800 2117 22277 ENG1

2120 42108 ENUR L 2120 ENUR L 2122 14702 AFCS 2145 ENG3 LUB QTY LOW 2145 HYDPWR 4

GT 21 47.14 734131 LTFR COMPUTER NOGO 20000400 GT 21 47.14 RTFR FAIL 20000400

2150 27272 ENG1 2152 ENG3 LUB TEMP HI 2233 46019 FUEL 2233 46039 FUEL 2256 14136 SCAS

2256 14152 SCAS 2304 14070 SCAS GT 23 18.09 FLR ANT NOT STOWED 44018000

FORM 2000-11-160 NEW 3-76 (PAGE 2)

Figure 19. CITS Printer Data.

DATE: 14 March 1978 CITS PRINTER DATA Sht 5 of 5

MESSAGE

1944 14690 SCAS 1954 45915 FUEL 1957 45962 FUEL 1903 32542 RIDS1 1903 46205 FUEL 1937 44404

1942 WING SWP 1943 14204 WING SWP 1949 46567 FUEL 1959 ENG2 LUB DTY LOW 2000 44211 ECS

2001 ENG2 LUB TEMP HI 2001 42263 GEN 2 2028 14263 FLAP/SLAT1 2024 14336 FLAP/SLAT1 2045 14077 SCAS

2101 41022 ECS SET TEMP

FORM 2000-0-160 NEW 3-76 (PAGE 2)

Figure 20. CITS Printer Data.

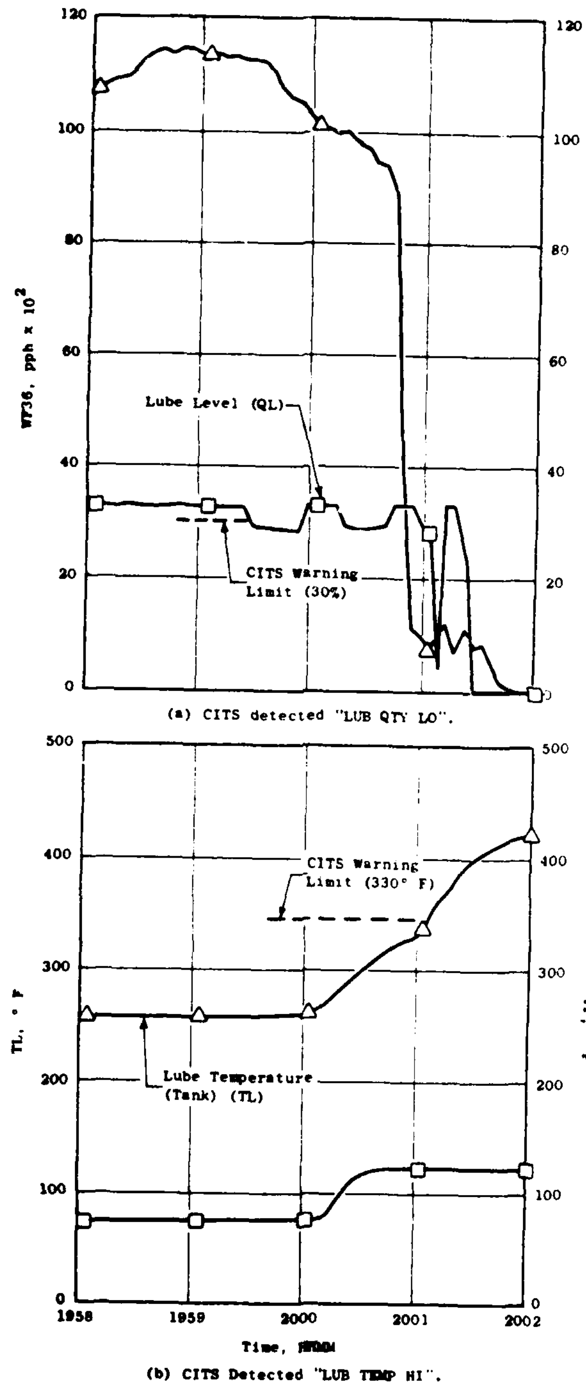


Figure 21. Case No. 1, Flight 1-68, Engine 3.

Case No.	Fault Class	Flight No.	Engine Position	Engine S/N
18	Mature	3-61	4	470-043
20	Mature	1-77	2	470-052
26	Mature	3-80	3	470-063
27	Mature	3-80	4	470-053
28	Mature	3-84	1	470-058

Cause: With the exception of Case No. 8, these events represent mature types of faults. Cases No. 7 and 20 were attributed to the ignition exciter, while Cases No. 13, 18, 20, 26, 27 and 28 were due to breakdown of the augmentor ignitor. Case No. 8 was attributed to a faulty switch in the main engine control which has since been designed out of the system.

Detection: These events were not detected due to the long dwell time (14 to 22 seconds) required by early steady-state logic and by the fact that pilot action removed the call for augmentor operation prior to satisfaction of the steady-state dwell time requirement. New transient logic has been developed that would detect all of these events as "No Aug.".

Isolation: Isolation would be correctly specified in eight of nine events as ignitor, exciter, flame detector. Case No. 8 would have been isolated incorrectly.

8. Hot Start - Broken Bleed Bias Line (One Event)

Case No. 9:

Statistics: Flight 3-33; Engine Position 4; Engine S/N 470-048

Cause: Problem tracked to broken bleed bias line.

Fault Class: Mature

Detection: CITS was off during this event. No data are available. CITS would have detected "T_{4B} High" or "Hot Start" during this event. A record of time and T_{4B} would have been taken.

Isolation: No isolation would have been indicated for this event. Some maintenance action may have been indicated by the T_{4B} temperature - time track.

9. Augmentor Pump Fuel Leak - (Three Events)

Cases No.: 1, 15, and 16

Statistics:

Case No.	Flight No.	Engine Position	Engine S/N
11	1-47	1	470-046
15	1-63	1	470-055
16	1-63	3	470-063

Cause: Problem was tracked to inadequate seal design. Seal was redesigned to eliminate thin section. No failures have occurred on the redesign seal.

Fault Class: Immature

Detection: This fault was not detected. There is no intent to detect this type of fault. All three cases were detected visually by the chase aircraft.

Isolation: No isolation was expected for this fault.

10. FDT Sensor Contamination - Engine Stall (One Event)

Case No. 12:

Statistics: Flight 3-47; Engine Position 2; Engine S/N 470-047

Cause: Foreign material (aluminum particles) was found in the flapper valve of the fan discharge temperature sensor causing erroneous IGV scheduling. A filter screen to prevent reoccurrence of this problem has been designed into the system. There have been no events of this type since screens were installed in the line.

Fault Class: Immature

Detection: This event went undetected because a 26-second steady-state period required in the logic at that time was not met. Present logic would have detected "NC versus NF Off-Schedule" (see Figures 22 and 23) prior to the stall although no message would be recorded other than "Eng 2." A "Low Thrust " indication might also have been detected during the periuod before the stall.

Isolation: Isolation for the "NC versus NF Off-Schedule" would have been to the basic engine if the current logic had been in use. The same isolation would result from a "Low Thrust" detection. See Figure 24 for the fault isolation logic. The correct isolation would have been to the T25 sensor for this fault.

11. Low Lube Level - Augmentor Fuel Pump Failure - (One Event)

Case No. 14:

Statistics: Flight 3-57; Engine Position 3; Engine S/N 470-057

Cause: Improper torqueing of pump impeller to shaft resulted in loss of axial clamping on oil seal, permitting it to rotate, machine material from internal parts, and degrade the impeller oil seal.

Fault Class: Immature - Torqueing procedure was corrected. No additional faults have occurred.

Detection: This fault was detected by CITS as "Eng 3 Lub Qty Low" (see Figures 25 and 26). Notice that CITS was "off" when lube level actually went below the warning level. The detection was made at 1815 hours when CITS was turned on. This fault was also detected visually by the chase aircraft.

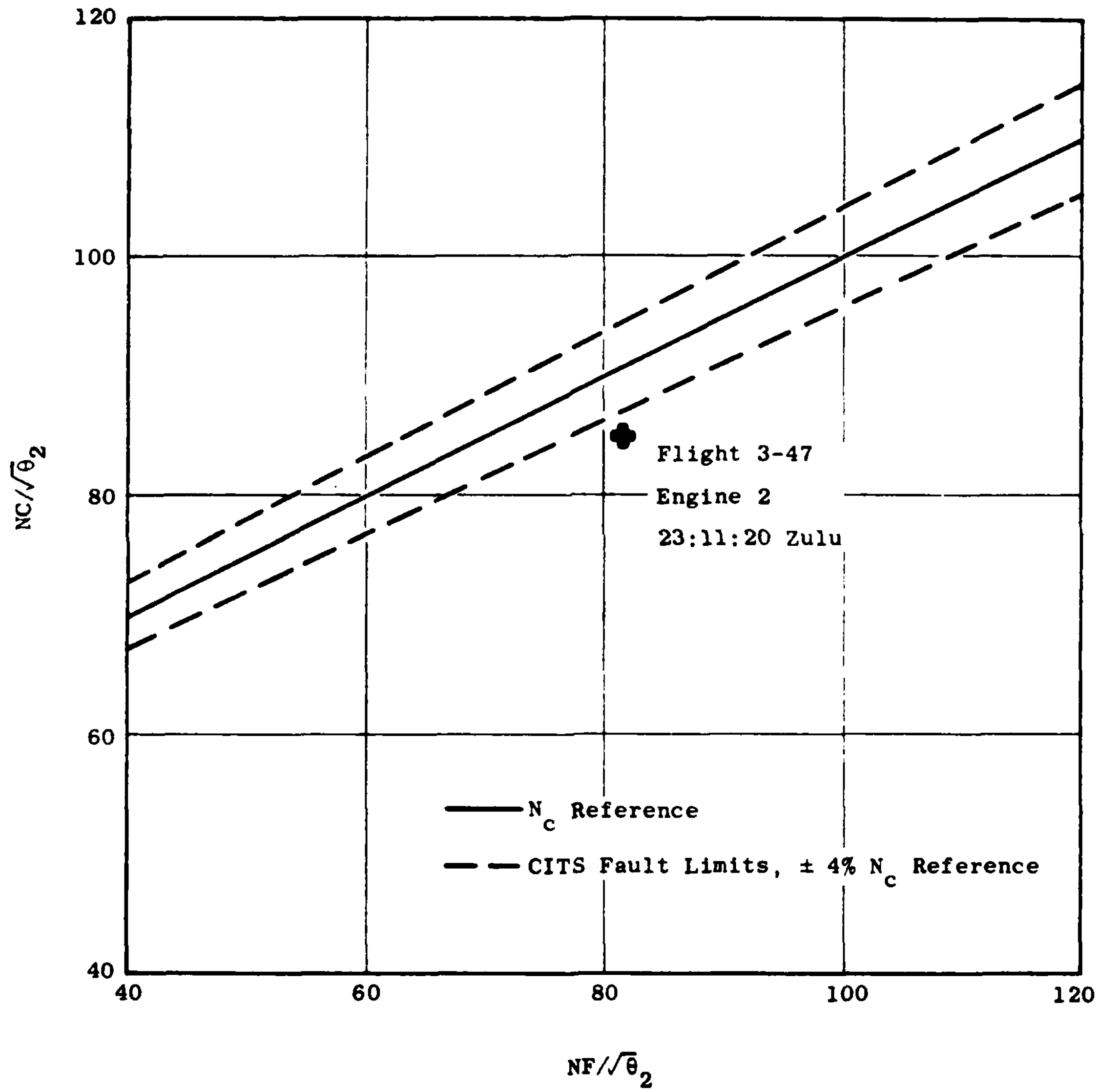


Figure 22. Corrected Fan Speed Versus Corrected Core Speed, Speed Ratio Reference for CITS.

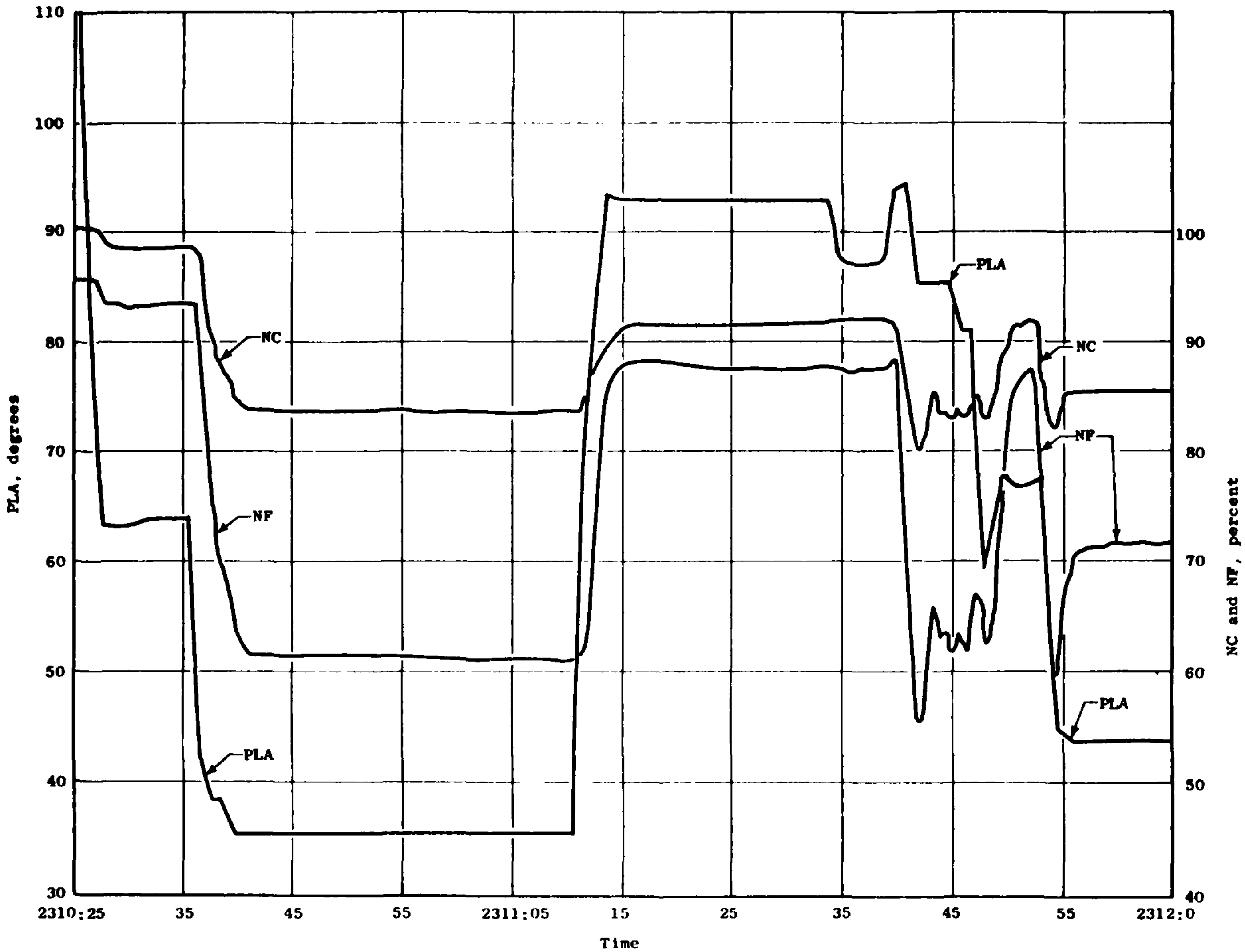
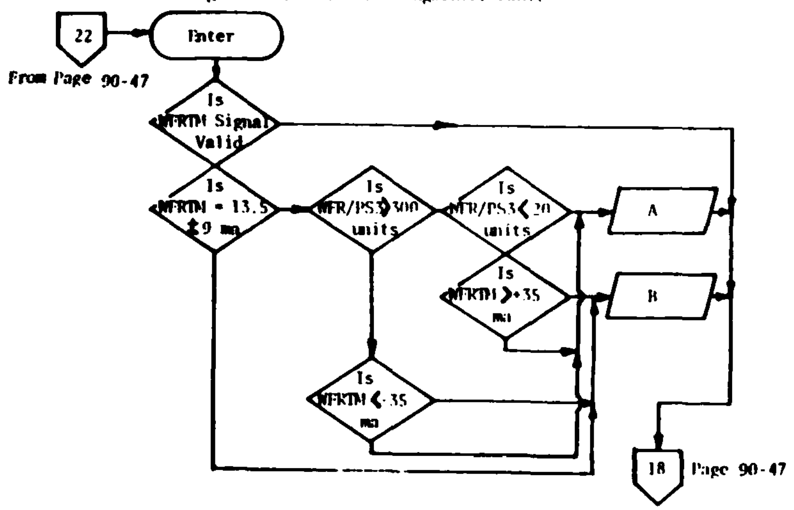


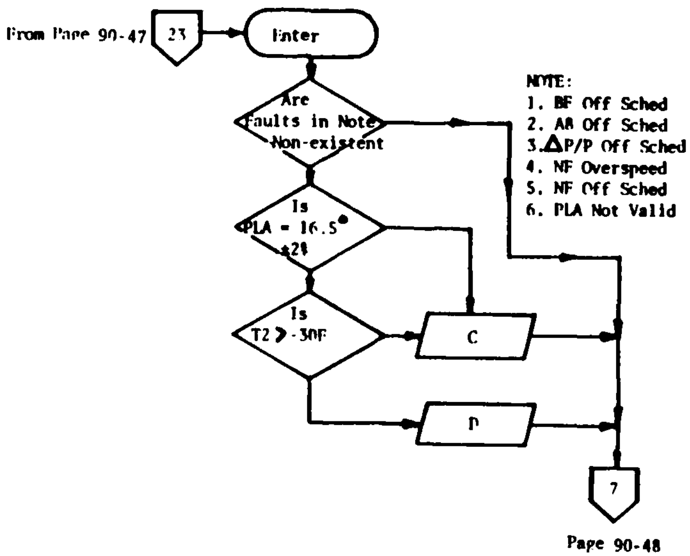
Figure 23. Flight 3-47, Engine 470-054 - NC and NF Versus Time.

GROUND AND IN-FLIGHT FAULT ISOLATION

Precondition: Aug + Nozzle Cont S/S Augmentor Fault



Precondition: Main Engine Control
S/S No-Go
Speed Ratio Off Schedule



INPUT/OUTPUT DISPLAY

I.D. No.	L Legend	M_1 Display	M_2 Display	I_m MFC Display	P
A	None	None	-	Aug Fuel Control	
B	None	None	-	AFTC	
C	None	None	-	Basic Engine	
D	None	None	-	T25 Sensor/MFC	-

Figure 24. Ground and In-flight Fault Isolation Subroutines.

FAT 3-57

CITS PRINTER DATA

DATE: 13 DEC 77 Sht 7 of 9

MESSAGE

1815 ENG4 THROT   1815 ENG4 THROT AUTO   1815 FIRE DETR 1   1815 23416 ENG1 THROT   1815 23419 ENG3 1

1815 23421 ENG3 THROT   1815 23422 ENG4 THROT   1815 49000 FIRE DETR 1   1815 14073 AFCS

2332/ = BE

1815 55000 CITS RCDR   1815 FUEL   1815 ENG3   1815 ENG3 LUB QTY LOW   1815 23321 ENG3   -- 1815 GEN 3

1815 42060 GEN 3   1815 46655 FUEL   1815 46027 FUEL   1820 46056 FUEL   1820 FLAP/SLAT1

1821 14349 FLAP/SLAT1   1821 14363 FLAP/SLAT1   1821 14340 FLAP/SLAT1   1821 14350 FLAP/SLAT1   1822 GCS

Figure 25. Flight 3-57, Augmentor Pump Lube Leak, CITS Printer Data.

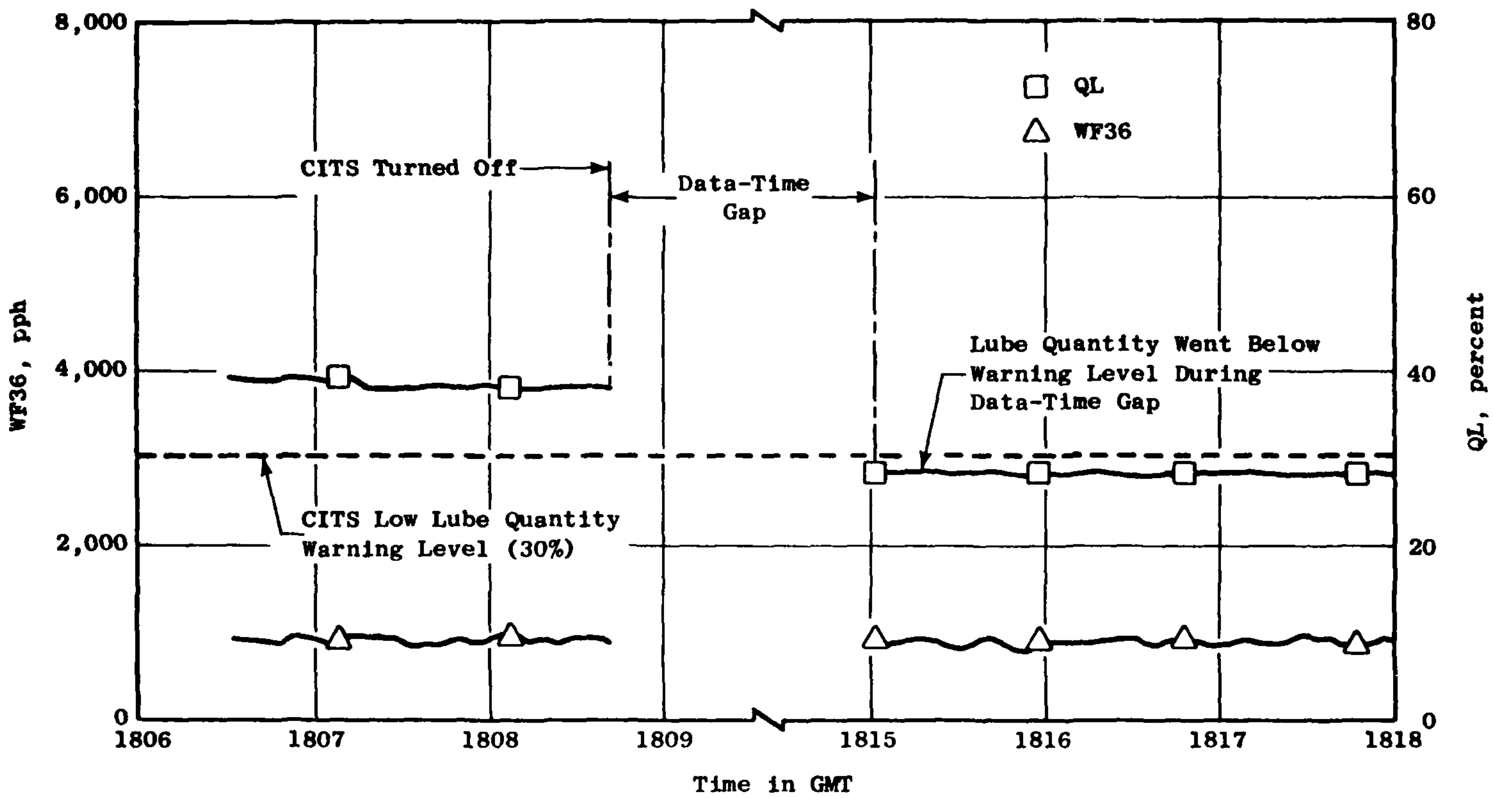


Figure 26. Case No. 14, Augmentor Pump Lube Leak - Flight 3-57, Engine 3 - CITS Detected "ENG 3 LUBE QTY LOW".

Isolation: This fault was isolated to the basic engine, "23321" (Figure 25), which is incorrect. CITS is not programmed to isolate this fault to the augmentor fuel pump which would have been the correct isolation.

12. No Start - Deteriorated Engine - (One Event)

Case No. 19:

Statistics: Flight 3-61; Engine Position 2; Engine S/N 470-061

Cause: Early main engine controls did not provide sufficient operating margin in the subidle regime to accommodate normal engine deterioration. A revised compressor stator schedule and accel fuel schedule in the main engine control achieved the desired results.

Fault Class: Mature

Detection: This event was detected by CITS as "Engine Slow/No Start" (see Figure 27). No data were recorded for this event.

Isolation: Proper isolation was indicated as "23259" (Figure 27), the main engine control. Specific gravity was adjusted and a successful start was made.

13. Unscheduled Shutdown - Main Engine Control - (One Event)

Case No. 29:

Statistics: A/C 3 Ground Test, 2-19-79; Engine Position 4; Engine S/N 470-052.

Cause: This event was caused by an improperly seated valve spring in the main engine control which seated properly during the ground run, resulting in a lean shift in the scheduled fuel and subsequent engine roll down. Spring seat design has been changed to prevent improper seating of the spring.

FLT 3-61

25 APR 1978

CITS PRINTER DATA

B-1 DATA SOURCE: TAPE NO 16D67-0003-106-5
A/V #160 FLT # 61 E.O.'s 200237
T/O 1825 (MT) LDG 0035 (GMT)
TEST REF. ______ SOURCE INSPECT. ______
TRANSLATOR Dale Young DATE 25 APR 78

DATA VALIDITY:
☒ PRELIMINARY-VERIFY WITH D/110.065
☐ VERIFIED AS IS
☐ VERIFIED AS MARKED
☐ VERIFICATION APPROVAL ______ DATE ______

MESSAGE

1624 HYDPWR 2 1624 45037 HYDPWR 2 1624 APU R 1624 APU R DISP 1624 23028 APU R 1624 SCAS

1624 14078 SCAS 1624 LDG STEER 1624 13005 LDG STEER 1625 HYDPWR 3 1625 45069 HYDPWR 3 1626 GEN 3

55

1626 41060 GEN 3 0000 HYDPWR SCOU 0000 45017 HYDPWR SCOU 0000 ECS RFT TEMP 0000 41037 ECS RFT TEMP

23259 = MFC

ENG1 0000 ENG1 SLOW NO START 0000 23259 ENG1 0000 ENG3 THROT 0000 23420 ENG3 THROT 0000 ENG3 THROT AUT

Figure 27. Flight 3-61, Fail to Start, CITS Printer Data.

Fault Class: Mature

Detection: There are no data available from this event. However, had CITS been activated, this event would have been detected as "Low Pwr Loss."

Isolation: Isolation is not programmed for this event.

SECTION IV

FLIGHT READINESS

The CITS flight readiness status was principally determined by the ground and in-flight thrust calculation logics in the CITS engine test. In the ground logic, the engine thrust is calculated and then compared to a reference curve representing a deteriorated engine. The results of that comparison determine the "Pass/Fail" status of the engine. In the in-flight logic, the engines are compared to each other when the engines are determined to be at approximately the same steady-state condition, and the "Pass/Fail" status is determined by comparing each engine's calculated thrust to the average of the group. (A minimum of three engines must be included to perform the test.)

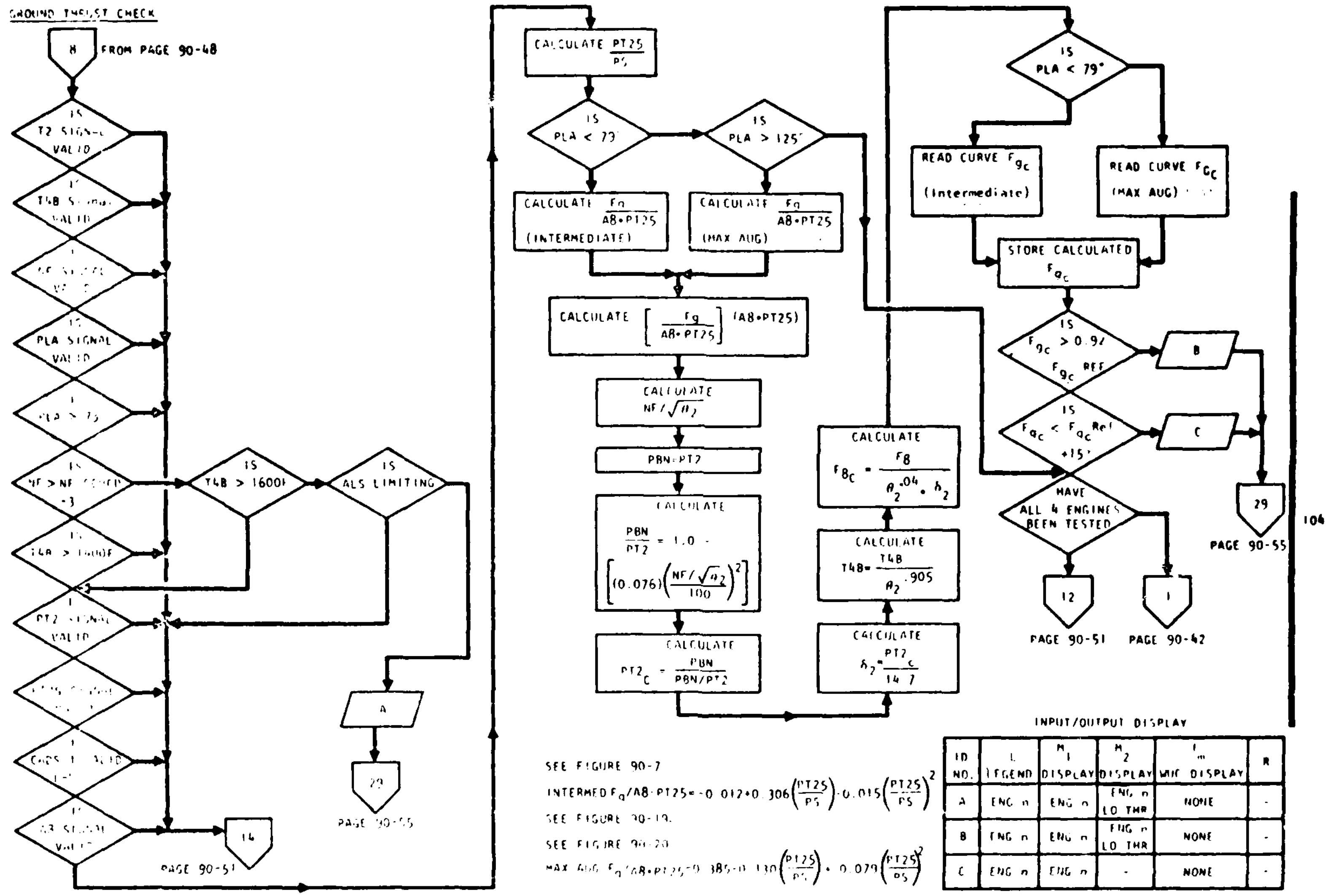
In this area, most of the effort in the B-1 flight test program has been directed toward obtaining satisfactory results from the ground thrust portion of the logic. The in-flight thrust calculation logic has not been the subject of any modification or study, and it has seldom flagged an engine for being low in thrust.

The alternate method used in the B-1 aircraft to determine flight readiness is also briefly discussed in this section.

A. GROUND THRUST DETERMINATION

During the course of B-1 flight testing, the ground calculated gross thrust reference curve was revised to provide a more realistic and reliable ground thrust level check. The following discussion explains the basis for the reference curve revision by using CITS ground thrust versus T_{4B} and comparing GE Edwards Flight Test Center (GEEFTC) test cell data with A/C ground data.

Figure 28 illustrates the ground thrust logic diagram and calculation procedure used in the CITS program.



SEE FIGURE 90-7

$\text{INTERMED } F_g/A8 \cdot PT25 = -0.012 + 0.306\left(\frac{PT25}{PS}\right) - 0.015\left(\frac{PT25}{PS}\right)^2$

SEE FIGURE 90-19.

SEE FIGURE 90-20.

$\text{MAX AUG } F_g/(A8 \cdot PT25) = 0.385 - 0.130\left(\frac{PT25}{PS}\right) + 0.079\left(\frac{PT25}{PS}\right)^2$

INPUT/OUTPUT DISPLAY

ID NO.	L LEGEND	M1 DISPLAY	M2 DISPLAY	Im WUC DISPLAY	R
A	ENG n	ENG n	ENG n LO THR	NONE	-
B	ENG n	ENG n	ENG n LO THR	NONE	-
C	ENG n	ENG n	-	NONE	-

Figure 28. Ground Thrust Logic Diagram.

Figure 29 presents the corrected gross thrust for YF101 engines determined from GEEFTC test cell data and takeoff data from Flights 1-53, 2-28, and 3-38. The spread in this curve is attributed to TC deterioration. Engines which have deteriorated tend to plot high in TC at constant thrust.

Table 9 ranks the performance based on the controlled temperature (TC) level of the YF101 flight engines compared at 6800 rpm corrected fan speed at the time thrust curves were being reviewed. This table, then current, lists the 23 flight engines in the order of their TC level. It can be seen that engines in this list have a current TC level that ranges from 1805° R to 1895° R. In addition, the average TC of the "as shipped" engines is approximately 1800° R.

Using the then-current TC ranking of the YF101 engines, data in Figure 29 are adjusted to 1850° R TC. This is accomplished by increasing or decreasing the corrected TC in Figure 29 by the amount TC deviates from 1850° R in Table 9. This adjustment tends to group the data into a single line which represents an 1850° R quality engine. The results are presented in Figure 30.

The solid line on Figure 30 is drawn through the lower limit of the test cell data. The dashed line on this plot represents the solid line (or an 1850° R quality engine) adjusted for B-1 installation effects. Installation effects include bleed, power, ram recovery, fan operating line, and soak time. These are illustrated on Figure 31.

The dashed line on Figure 30, as mentioned above, represents an 1850° R quality engine installed in the B-1. Even though A/C data in Figure 30 show more spread than test cell data, the dash line appears to be a good representation of the lower limit of the A/C data.

As stated earlier, the average TC of new engines is approximately 1800° R. Using the general derivative for thrust, 10% thrust loss is equivalent to 100° F deterioration. Therefore, engines which exceed 1900° R in the TC quality ranking have lost approximately 10% thrust since new.

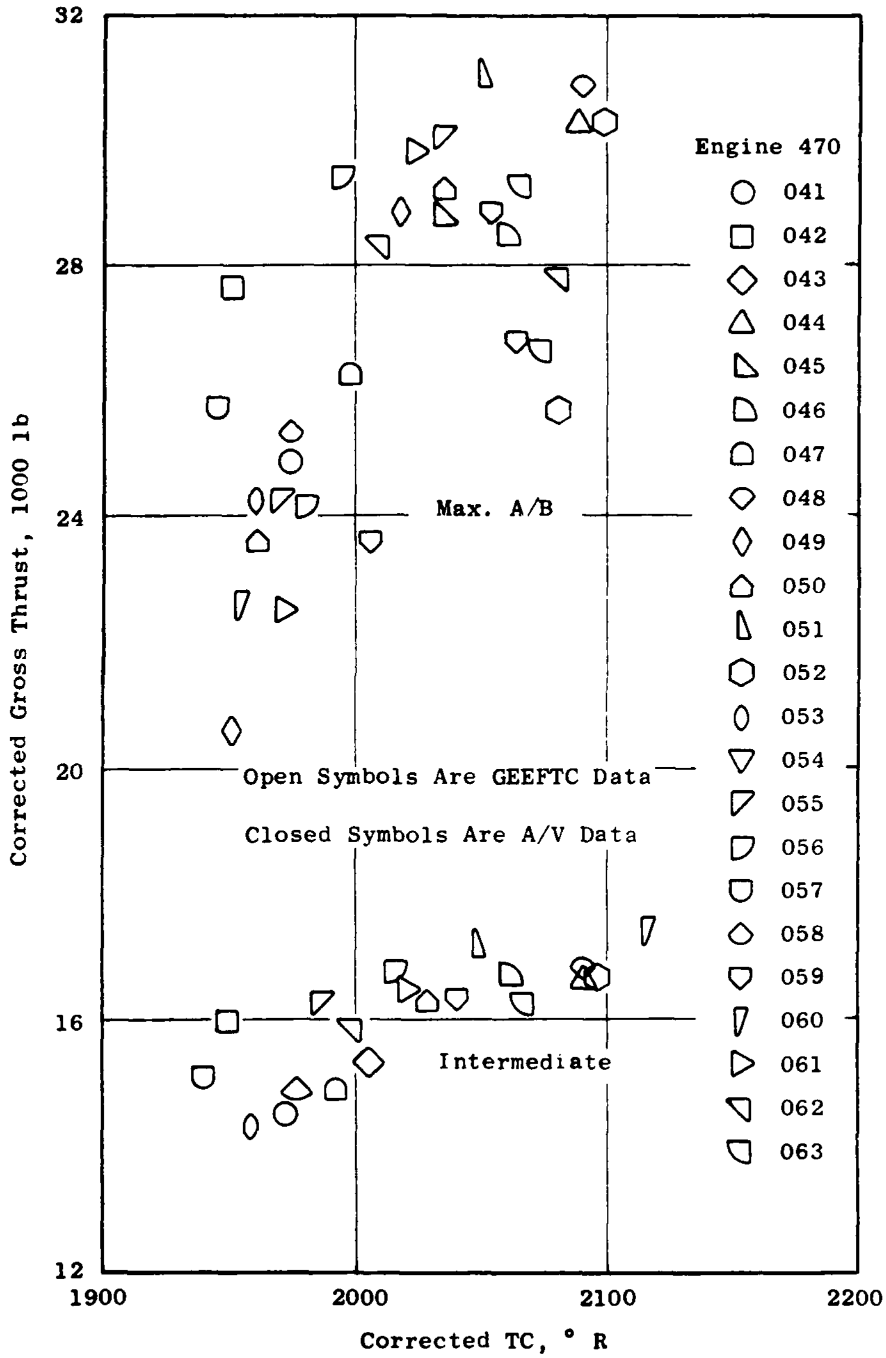


Figure 29. YF101 Engine Data.

Table 9. YF101 Engine TC Performance Ranking as Tested at 6800 RPM, Date 09-01-77.

Engine S/N	As Shipped TC, ° R	Current TC, ° R	Test Cell Date or Flight No.	Run Hours
470-042	1795	1805	06-28-77	195
470-055	1825	1810	FLT-1-56	220
470-056	1790	1810	FLT-1-56	236
470-059	1830	1815	FLT-1-56	238
470-054	1805	1820	08-15-77	200
470-057	1810	1825	08-03-77	168
470-050	1810	1840	FLT-2-28	137
470-062	1792	1840	06-16-77	196
470-045	1845	1845	04-05-77	195
470-049	1760	1850	07-07-77	330
470-061	1765	1850	FLT-1-56	218
470-052	1790	1860	FLT-3-40	258
470-048	1785	1860	FLT-2-28	253
470-058	1768	1860	07-11-77	130
470-063	1770	1863	FLT-3-40	125
470-053	1790	1865	06-22-77	300
470-043	1795	1870	FLT-3-40	292
470-044	1755	1870	FLT-3-40	265
470-060	1785	1875	FLT-2-28	221
470-051	1782	1875	02-10-77	165
470-041	1800	1876	08-09-77	280
470-047	1770	1878	06-01-77	280
470-046	1822	1895	FLT-1-48	214

Note: These data are adjusted to 1850° R using the TC ranking table.

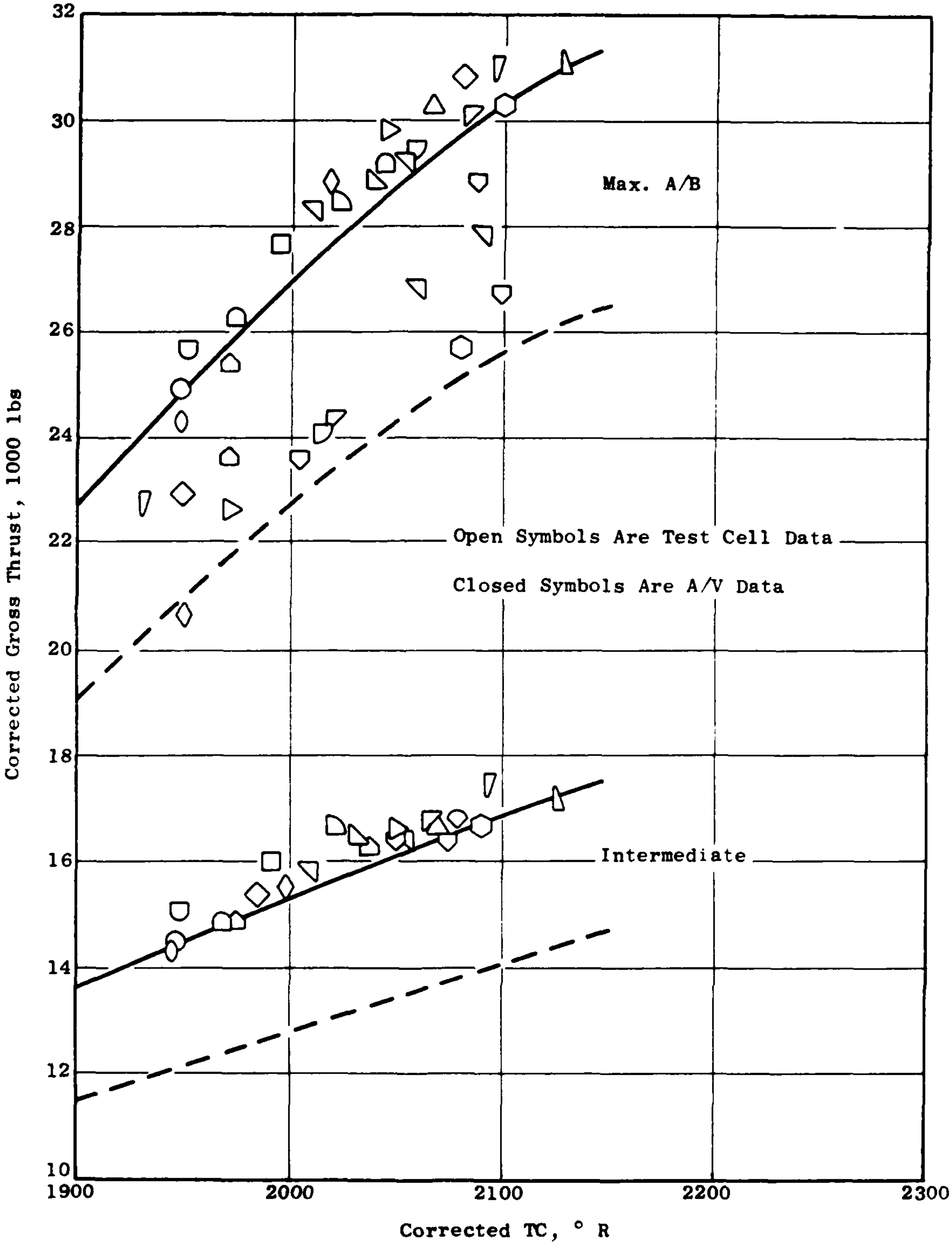


Figure 30. YF101 Engine Data Adjusted to 1850° R.

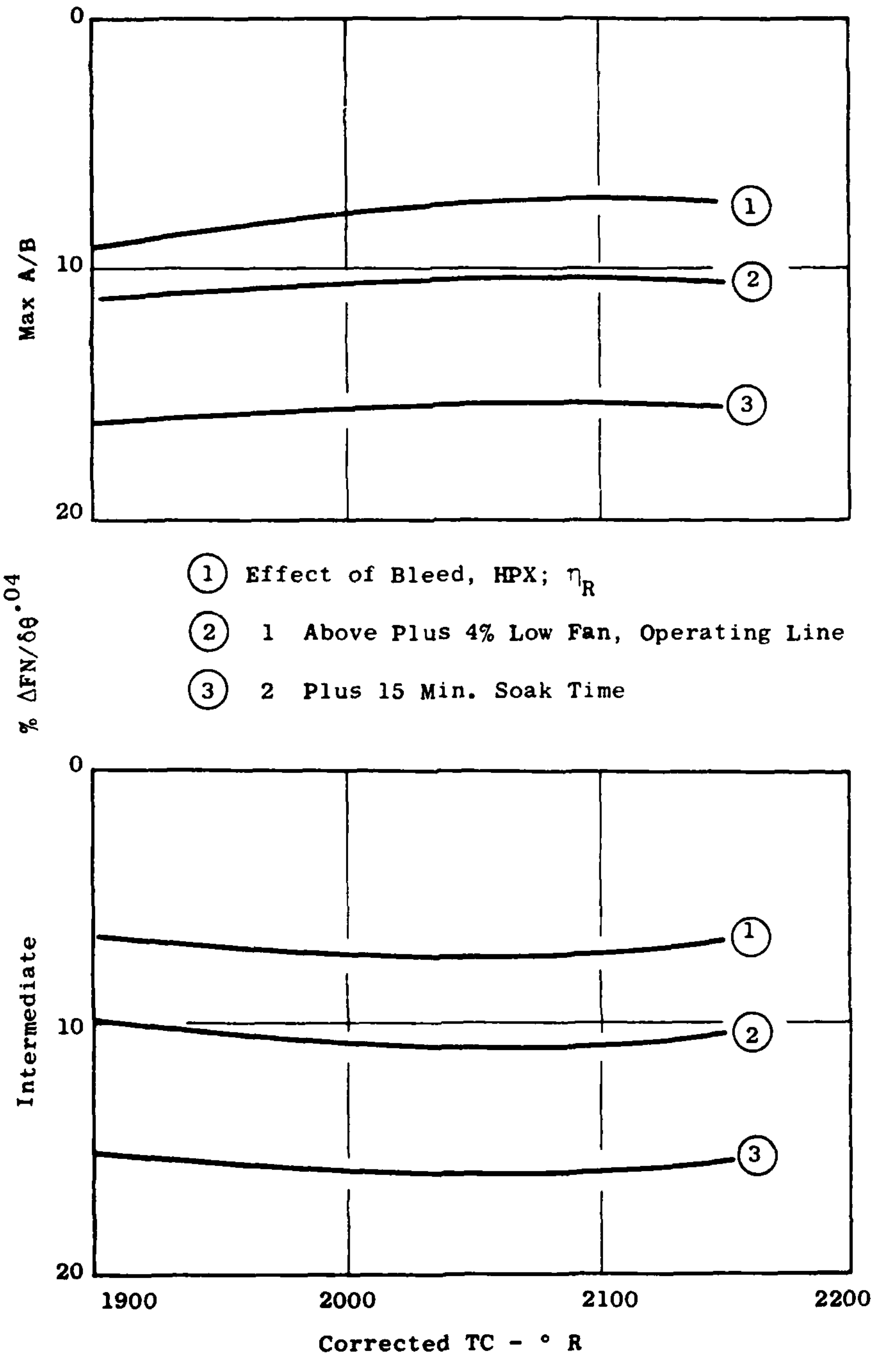


Figure 31. Installed Effects - YF101 Engine Based on Cycle Program and 470-041 Soak-in Data.

Figure 32 presents the estimated thrust limit curves for a 1900° R or a 10% thrust deteriorated engine; these curves are hereafter referred to as the "new" curves. These curves replaced the original reference curve ("old" curves) used to check ground thrust in the CITS program and were introduced to the A/C 4 software package for Flight 4-12 and subsequent flights.

However, data from 4-12 and subsequent flights could not be reduced by General Electric due to format changes made by Rockwell International which were not communicated to General Electric.

One lesson learned during the development of the CITS system is that changes in software need to be implemented and tested at a rapid rate or the total development time required will suffer.

Also, communication between the aircraft and engine CITS groups needs to be more effective regarding changes in output format which reflect the analysis and conclusions drawn from the CITS data.

1. Flight 3-51 - Check of Ground Thrust Limits

Prior to requesting a change to the ground thrust limit curves, a study was conducted to determine if the curves were valid when actual flight data were processed by the CITS logic. A time-sharing computer program was written to postprocess actual CITS flight data using logic identical to that being recommended for use on the aircraft. The test case selected was Flight 3-51 since the engines installed for that flight were of various quality levels as shown below:

A/C Pos.	Eng. S/N	TC Ranking*	Total Running Time, hr	Time Since TC Ranking, hr
1	053	1890	332	8
2	058	1810	142	0
3	057	1840	219	51
4	044	1860	300	20

*Ranking at 6800 rpm fan speed ~° R

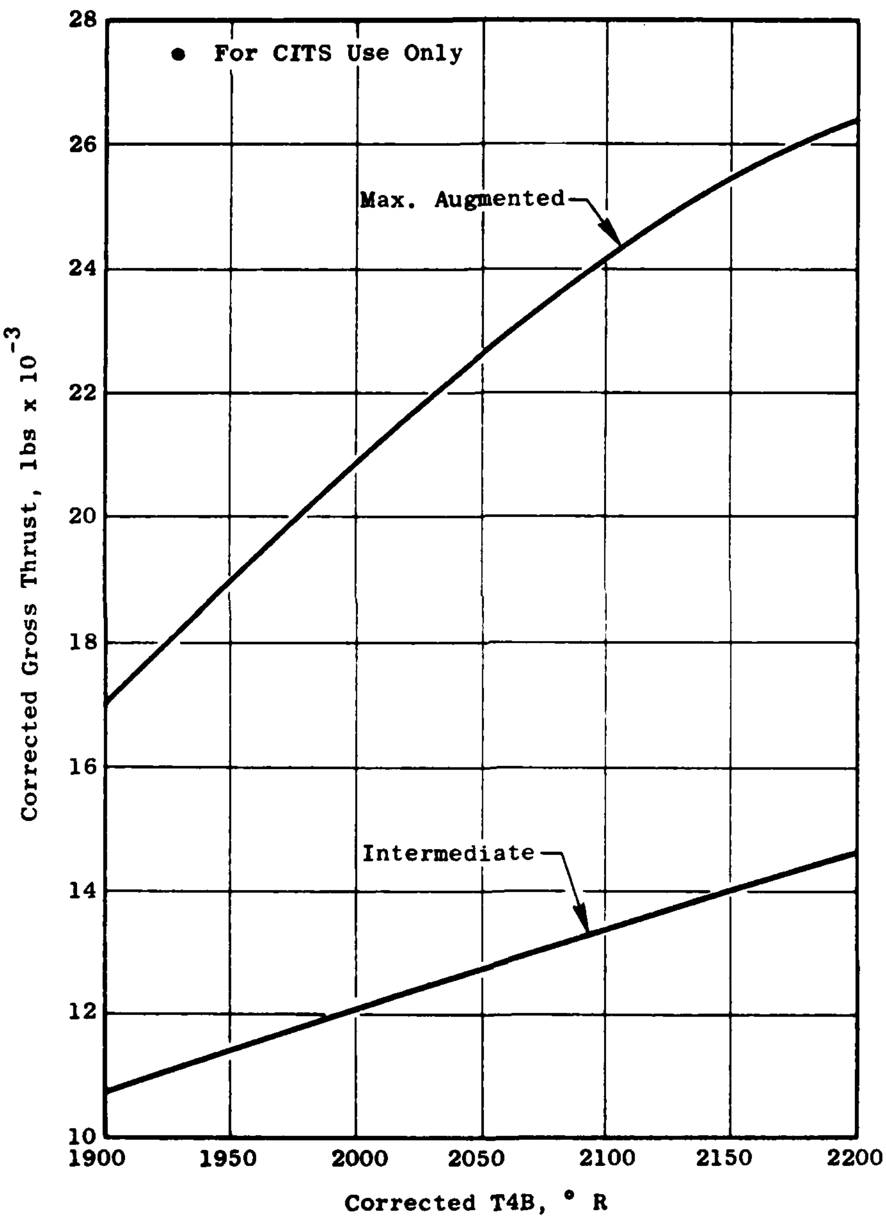


Figure 32. Ground Gross Thrust Versus T_{4B} Limit (SLS-Installed).

A plot of percent thrust margin versus time for Flight 3-51 takeoff is shown in Figure 33. Note that Engine 1, which has a TC ranking of 1890° R, is very near the 0% line and would probably dip below it, causing a "low thrust" output on CITS when this engine deteriorated to the 1900° R limit. The other three engines are in the correct relative position based on their measured TC ranking. Seventeen seconds into the takeoff is the first possible time the CITS logic would check the data due to the steady-state time criteria; it is data from this time-point that are plotted in Figure 34 on the then-proposed ground thrust limit curves.

2. Flight 3-93 - Low Thrust Indications During Takeoff

"Low Thrust" messages were outputted by CITS for Engines 1, 3, and 4 prior to and during the takeoff of Flight 3-93 (Figure 35). Since all engines were known to be of good quality, as indicated by the data shown below, it was not expected that any of them would be flagged for "low thrust" by the CITS.

A/C Pos.	Eng. S/N	TC Ranking*	Total Running Time, hr	Time Since TC Ranking, hr
1	058	1835	230	130
2	086	1830	81	18
3	061	1840	372	36
4	054	1815	445	20

*Ranking at 6800 rpm fan speed ~° R.

An analysis similar to that done on Flight 3-51 was completed; the results are summarized below and plotted in Figure 34. Note that Engine 3 was flagged for "low thrust" at intermediate power while all other data considered have been at maximum augmentor power, the normal power setting for takeoff. All data presented are at time of the CITS indication. The data show that only Engine 1 should have been flagged for "low thrust," using the old thrust reference curves, but that none of the engines would have been flagged using the new thrust reference curves. It is not understood from the data available why Engines 3 and 4 were flagged in this flight.

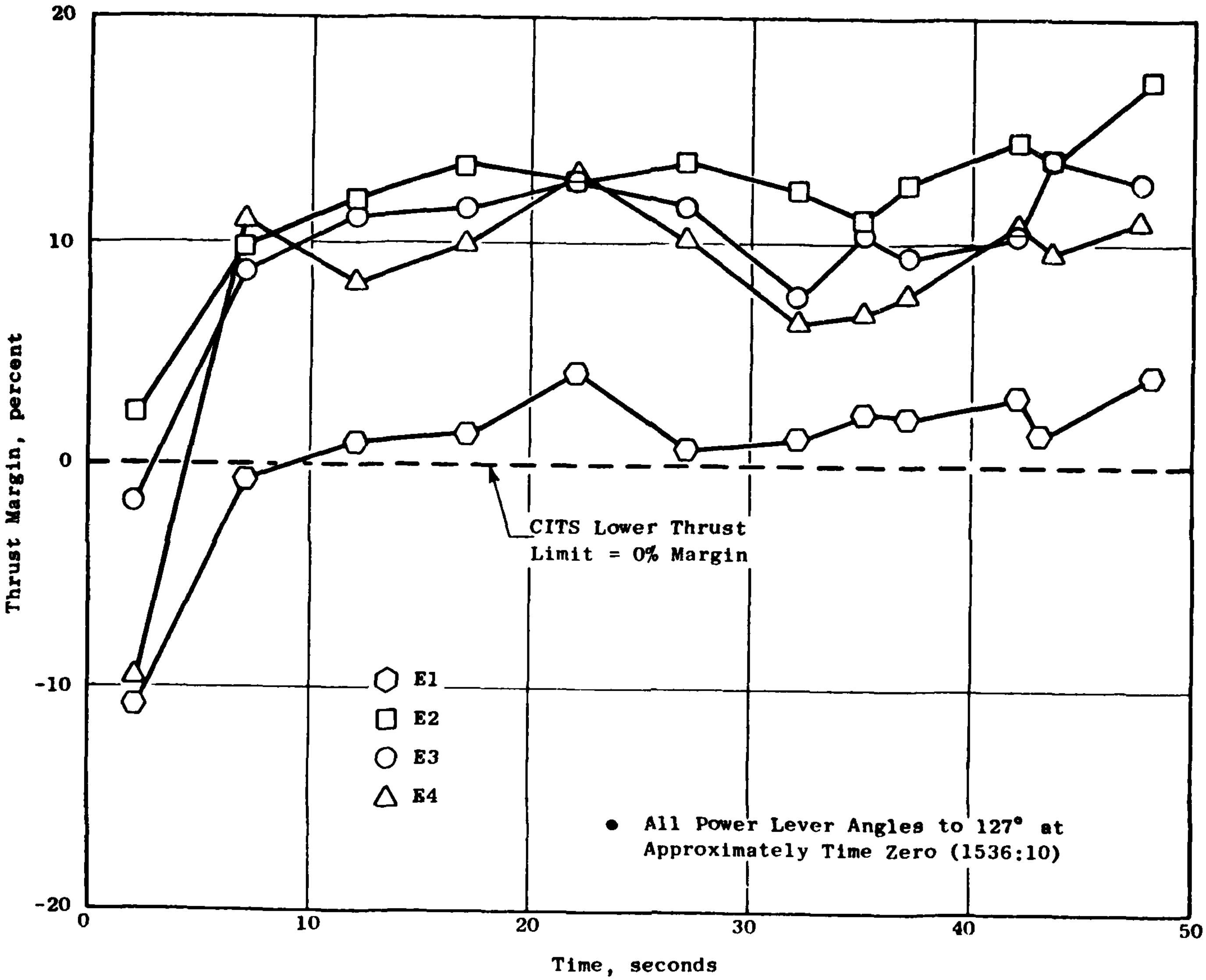


Figure 33. CITS Thrust Check Flight 3-51, 10-18-77, Takeoff Roll.

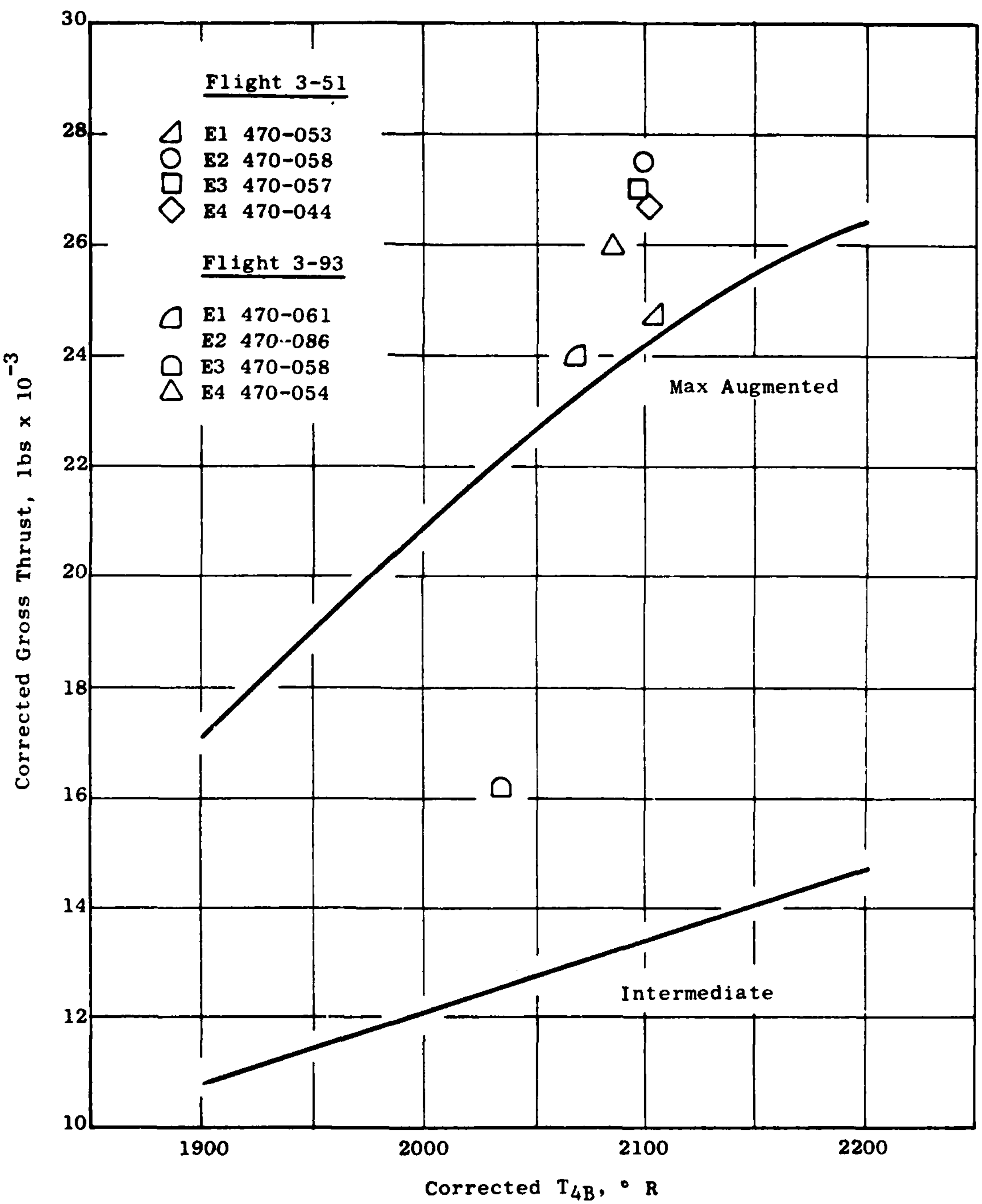


Figure 34. Ground Gross Thrust Versus T_{4B} Limit (SLS-Installed).

DATE: 3-13-79

CITS PRINTER DATA

Sht 6 of 11

MESSAGE

1757 FIRE DETR 1   1757 49000 FIRE DETR 1   1757 ENG3   1757 ENG3 LOW THR   BE 1757 23321 ENG3

1757 ENG2 SIG FAULT   CITSP 1757 23293 ENG2   1758 41177 ECS   1758 ENG2 THROT   1758 ENG2 THROT AUTO

1758 23418 ENG2 THROT   1758 ENG1   1758 ENG1 LOW THR   1758 ENG4   1758 ENG4 LOW THR

1759 ICE DETR L   BE 1759 23353 ENG4   BE 1759 23257 ENG1   1759 23452 ICE DETR L   GT 17 59 15

NAV FLT CAUTION   10000000   1759 14353 FLAP/SLAT1   1759 14348 FLAP/SLAT1   1800 14236 FLAP/SLAT1

FORM 2000-11-160 NEW 3-78 (PAGE 2)

Figure 35. CITS Printer Data.

A/C Pos.	CITS Corrected Thrust - lb(1)	Old CITS Ref. Thrust - lb(2)	Old Thrust Margin, %	New CITS Ref. Thrust - lb(3)	New Thrust Margin, %
1	23,971	24,284	-1.3	23,231	+3.2
3	16,158	12,516	+29.1	13,397	+20.6
4	25,926	24,423	+6.2	23,714	+9.3

(1)As calculated by logic shown in Figure 28.

(2)Ground thrust limit curves used prior to Flight 4-12.

(3)Ground thrust limit curves used for Flight 4-12 and subsequent flights, and for flights shown in Figure 34.

It can also be seen that the intermediate power thrust limit curve needs to be revised again since no engine should be 20% above the 10% deteriorated curve. The thrust of a new engine could be expected to be as much as 15% greater than the curve due to engine-to-engine variation as well as differences in installation effects from one A/C position to another in any given flight.

B. IN-FLIGHT THRUST DETERMINATION

Search of the flight data did not locate any instances of engines being flagged for high or low thrust during flight when the engine in-flight thrust logic would be used. To test the logic, a sample case using flight data was manually processed using the logic calculation procedure. The results of this exercise were then compared to similar results obtained from the engine cycle deck (computer math model of engine's thermodynamic cycle). Results are summarized on following page.

Review of the data shows that the CITS in-flight gross thrust calculation varied from +5.4% to +15.1% from that calculated by the engine cycle deck for a new engine running at the same fan speed and the same inlet conditions. This is not surprising, for the CITS calculation was designed to give only an approximate answer and to use only a minimum of calculation effort. With this in mind, the CITS method looks much better than the data would first indicate. The corrected and adjusted corrected thrust is an abstract parameter that was selected to make the engine-to-engine comparison

Time = 1848 hrs Mach = 0.71 Altitude = 29,880 ft Avg. PLA = 59.5°

	E1	E2	E3	E4
CITS Gross Thrust (F_g)	8934	7728	8113	8657
Cycle Deck F_g	7764	7019	7401	8209
Δ from Cycle Deck - %	+15.1	+10.1	+9.6	+5.4
Corrected Thrust (F_gK)	22,033	19,007	19,386	20,958
Adjusted F_gK	21,495	19,789	20,121	19,812
CITS "Low" F_g Limit	18,274	18,274	18,274	18,274
CITS "Hi" F_g Limit	23,350	23,350	23,350	23,350
Result of Test	Pass	Pass	Pass	Pass

against the limits. Once the average adjusted corrected thrust is determined for the number of engines being tested, the low and high limits are set at 90% and 115% of the average. In this case all engines passed the test: their adjusted corrected thrust was within -10%/+15% of the four-engine average adjusted corrected thrust.

C. "POWER LEVEL UNIT" COCKPIT GAGE

The most reliable indication of ground readiness for flight in the B-1 flight test program has been the cockpit power level unit (PLU) gage. This parameter was developed for the B-1 program since a classic engine pressure ratio (EPR) gage is not adequate for an engine with variable exhaust nozzle geometry. The PLU gage was designed to automatically calculate a gross thrust indication and thereby reduce the pilot's workload. Without a PLU gage, the pilot would be required to read EPR and A_8 from cockpit gages, determine ambient conditions P_{T2}, T_{T2} and arrive at a minimum required EPR and A_8 from tables prior to takeoff.

The PLU value is calculated from:

- Measured fan pressure ratio (FPR) using fan discharge pressure (P_{T25}) and fan inlet pressure (P_{T2}).
- Measured exhaust nozzle area (A_8) using actuator stroke measurement.

- Measured engine inlet temperature (T_{TO}) using aircraft free stream total air temperature.

The calculation flow diagram for PLU is shown in Figure 36; the supporting correction curves are shown in Figures 37 and 38. Nominally, a new engine will have a PLU of 5.0 at intermediate and 10.0 at max augmentor on a standard day.

Using the PLU gages the pilot can readily get a comparison from engine to engine, both on the ground and during flight, and can also compare the PLU of the installed engine to nominal new engines prior to flight.

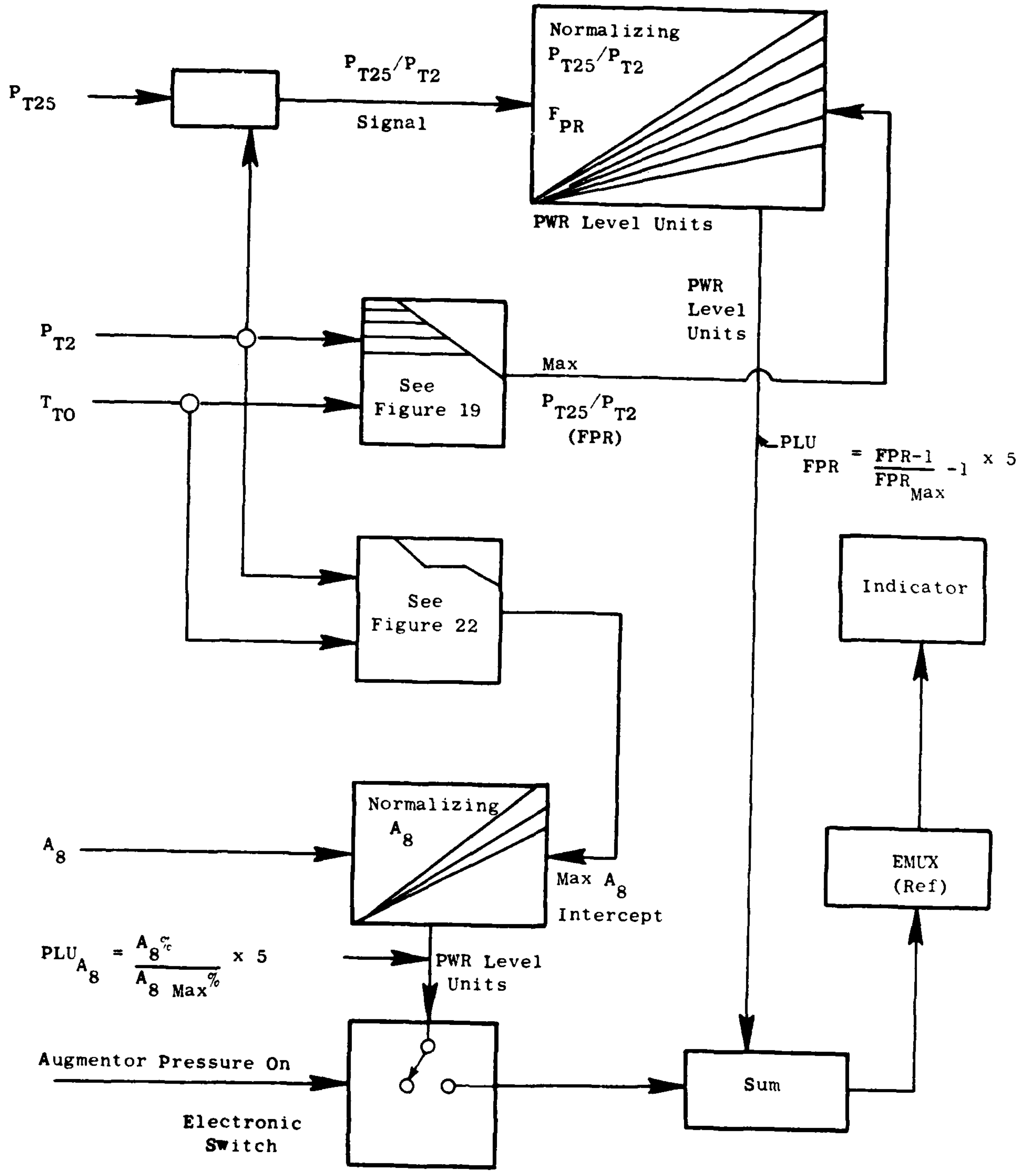


Figure 36. Power Level.

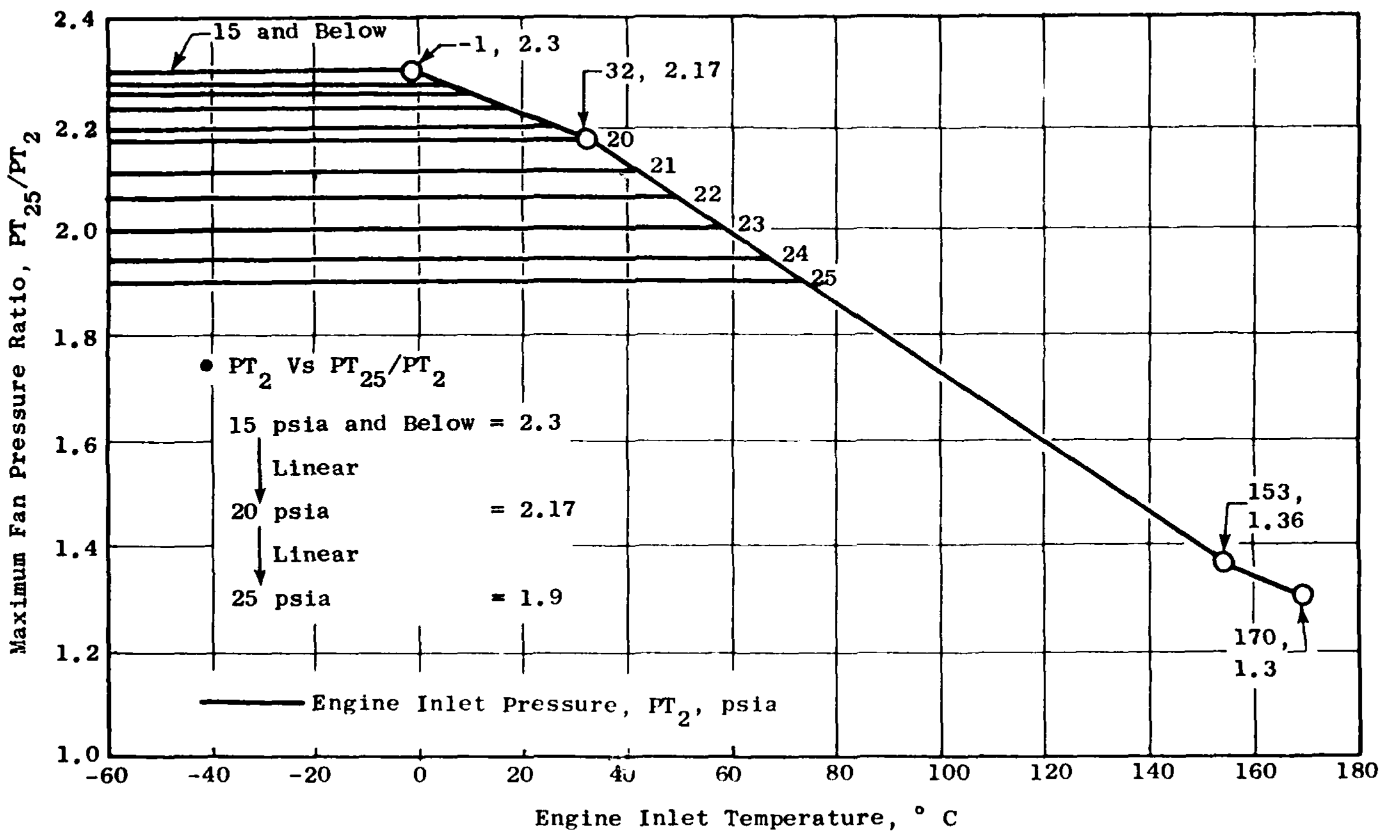


Figure 37. Determination of Maximum Reference Pressure Ratio.

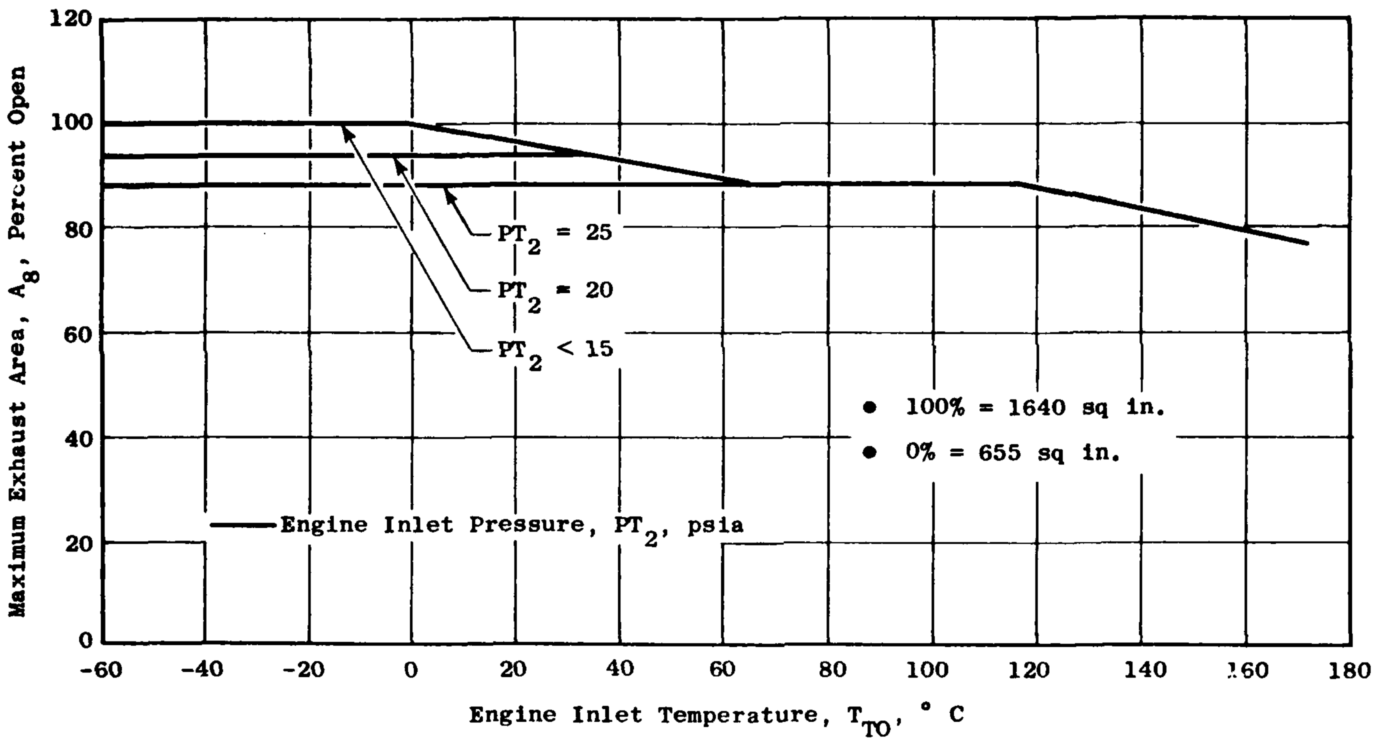


Figure 38. Determination of Maximum Reference Exhaust Area.

SECTION V

LOW CYCLE FATIGUE CYCLE AND TIME AT TEMPERATURE COUNTING

Low cycle fatigue (LCF) cyclic exposure has long been understood to be an important contributor to engine life consumption. For this reason, the CITS was to automatically keep track of certain predefined LCF parameter cycles during each flight so that accurate records could be kept for each engine, by S/N, on its cyclic life-limited parts as they related to the LCF cycles reported. Unfortunately, the CITS software implementation of this cycle counting logic has not been successfully incorporated as of October 30, 1979, and the only LCF tracking of the flight test engines has been done by postprocessing the CITS tapes by General Electric.

The only "time at temperature" counting that was to have been done by CITS was that done in an engine overlimits condition. Were the engine to experience either a fan or core overspeed condition or a turbine blade (T_{4B}) overtemperature condition, the CITS was to record the out-of-limits parameter every quarter-second that the engine was in such a condition. There was no provision in CITS to record time at rated turbine temperature data for the engines.

A. CITS LCF CYCLE COUNTING

CITS software provides for counting of four different types of LCF cycles:

- Core Speed (NC) <20%, >58%, <20%
- Fan Speed (NF) <55%, >95%, <55%
- Turbine Blade Temperature (T_{4B}) <1000° F, >1500° F, <1000° F
- Power Lever Angle (PLA) <21° F, >71° F, <21° F

The NC cycle is designed to count engine starts and should, therefore, only register 1 full cycle per flight unless multiple ground starts or air starts were made as part of the normal flight plan. The NF cycle detects fan speed changes from slightly above idle to slightly below intermediate, assuming you are not operating in the inlet temperature range where NF is cut back by the control system schedule (Figure 4). The T_{4B} cycle simply counts partial thermal cycles on the turbine blades. The PLA cycle has become the most important LCF measurement to the YF101 and F101 engines in the B-1 Flight Test Program. This measurement, which counts full cycles from idle power to intermediate power and back, is rapidly becoming one of the primary parameters when evaluating different missions, test cycles, or engine exposure. Because of the importance of the PLA cycle, it has always been tracked by GE using a postflight processing routine of the CITS flight test tapes and recently (Flight 4-12) was substituted for the compressor discharge pressure (P_{S3}) cycle that has been used during all previous flights.

1. Flight 2-60

Prior to Flight 2-51, the LCF logic would only count the first half-cycle of the four types; after that point, no further outputs would be made. On Flights 2-51 through 2-60, LCF counts were being recorded by CITS, but they did not agree with those being obtained by postprocessing of the flight test tapes. In an effort to better understand the problem, a study was made using the data from Flight 2-60.

The data from Engine 2 (the only engine analyzed) were plotted on a continuous plot against time for the period from 1700 hours to 1850 hours inclusive. Examination of this plot indicated the problem must be in the CITS cycle counting logic since it appeared that data spikes, or dropouts, may be causing the false LCF outputs. A summary of the data shows the following LCF activity in the time period studied:

	T_{4B}	NF	NC	P_{S3}
CITS LCF Bit Changes	7	7	9	3
Review of Plotted Data (less dropouts)	5	4	1	1
Due to Dropouts Alone	-	-	4	-

In interpreting the data, the significance of an "LCF Bit Change" must be known and realized that the continuous data plot was made from data recorded every 5 seconds whereas the CITS software accesses fresh data four times per second. A "bit change" is outputted each time one of the LCF parameters completes a half cycle - that is, each time a cycle limit is equalled or exceeded in the appropriate direction. At startup, for example, once NC passes from <20% to >58% (normal idle ~ 63%), a bit would be output; for the next NC bit to be output, the core speed must drop below 20% to reset the >58% logic and to output the second NC bit. If the core speed would cycle between 40% and 100%, no LCF bit changes would take place - thus two bit changes or "counts" equal one complete cycle.

A review of the flight (2-60) profile indicates that it is doubtful if the every-5-second data masked any LCF cycles. The flight legs flown in this data sample studied consisted of the following:

- Ground Start and Taxi
- Takeoff and Climb
- Cruise
- Idle Descent for Terrain Following

The results of this study were communicated to RI and logic changes were introduced for Flight 4-12.

2. Flight 4-12

Due to the problems in reducing the data from Flight 4-12 and subsequent flights, a fair evaluation of the success of the LCF logic changes cannot be made; but it is obvious that the LCF counting function is still not working correctly. GE was able to successfully reduce 43 data points in the time period from 1741 through 1830 hours where a total of 588 data points would normally be expected. There was no problem in reducing the LCF bit change output. A continuous plot of the limited amount of data was made and comparison similar to Flight 2-60 was completed. Results are summarized in Table 10.

Table 10. LCF Summary for Flight 4-12.

Type LCF Cycle	Indicated Number of Bit Changes				CITS Reported Bit Changes				Difference (CITS-Indicated)			
	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4
NC	1	1	1	1	3	7	7	17	+2	+6	+6	+16
NF	3	3	3	3	18	13	17	6	+15	+10	+14	+3
T_{4B}	3	3	3	3	1	5	7	13	-2	+2	+4	+10
PLA	3	3	3	3	3	7	7	11	0	+4	+4	+8

Since there were no air starts or multiple ground starts in this time period (based on Flight Test Engineers' notes), it can be readily seen that the NC counting logic cannot be working correctly. The extra data do not appear to be realistic since the aircraft only took off, climbed to 25,000 feet, cruised to China Lake at 25,000 feet, and made an idle descent in the first 30 minutes of the 39-minute data segment studied.

B. CITS TIME AT SPEED/TEMPERATURE COUNTING

CITS was to record data each time one of the three parameters exceeded a fixed limit as indicated below:

- NC - Core Speed Greater than 106%
- NF - Fan Speed Greater Than 104%
- T_{4B} - Turbine Blade Temperature Greater than 1650° F (898.9° C)

Although there have been no instances of overspeed and few instances of overtemperature in the B-1 Flight Test Program, it appears that the CITS has not been working since GE has been unable to extract such information from the CITS flight test tapes. In the few engine overtemperature events to date, data from other flight test instrumentation systems have provided much more data than would have been available if CITS data were the only source.

C. POSTFLIGHT PROCESSING OF CITS TAPES TO OBTAIN LCF AND TIME AT TEMPERATURE DATA

GE developed a computer program to postflight process the CITS tapes early in the B-1 Flight Test Program to obtain LCF and time-at-temperature data. The three data sets that were output by this program are shown in Figure 39 for Flight 3-97.

The first output is the number of PLA half-cycles for the flight. This first data set shows that the four engines had 11, 10, 13, and 13 full cycles for Engines 1 through 4, respectively. The second set of output shows the time-at-temperature data for the flight. The four output categories yield the following information:

- PLA - This gives the total time when PLA was greater than 72° and 79°. That is the time at intermediate power and above (>72°) and the time at augmented power (>79°).

*CITS CYCLES AND TIME AT TEMP. FLIGHT 3 -97 *

	ENG #1	ENG #2	ENG #3	ENG #4
PLA	22	20	26	26

*CITS CYCLES AND TIME AT TEMP. FLIGHT 3 -97 *

		ENG #1	ENG #2	ENG #3	ENG #4
PLA	72.00	1.3717	1.3660	1.2856	1.2426
	79.00	0.2697	0.2520	0.1675	0.1559
T4B	815.50	2.2383	2.1302	2.1542	1.7607
	840.50	1.7205	1.6252	1.6604	1.4016
	851.70	1.5778	1.4503	1.4843	1.2860
	862.80	1.4255	1.1240	1.3435	1.1751
	868.30	1.3621	0.9559	1.2928	1.1319
	873.90	1.2813	0.8187	1.2254	1.0229
	879.40	1.1904	0.4227	1.1469	0.8369
	887.80	0.0006	0.0006	0.0006	0.
T3	800.00	6.2780	6.2850	6.2268	6.2642
	1000.00	1.7170	2.0149	1.8260	1.7511
	1050.00	0.9501	1.1803	1.0560	1.0401
80	1075.00	0.6234	0.9012	0.5847	0.7566
	1100.00	0.0402	0.3016	0.0367	0.1145
	1125.00	0.0020	0.0033	0.0020	0.0020
	1150.00	0.0020	0.0020	0.0020	0.0020
MN	1.00	0.	0.	0.	0.
	2.00	0.	0.	0.	0.

P1188-02

*** TIME DISCONTINUITIES FOR THIS CITS TAPE ***
* FROM TO *

16 43 39.68 - 16 46 4.92
20 02 32.30 - 21 02 41.35

Figure 39. CITS Tape Postflight Processing Outputs.

HONEYWELL PAGE PRI

- T_{4B} - This gives the time that T_{4B} exceeded the minimum temperature (° C) shown for each band.

- T_3 - This gives the time that a calculated T_3 exceeded the minimum temperature (° F) shown for each band. Note that there is no T_3 instrumentation included in the CITS on engine instruments subsystems. There is, however, an adequate amount of data to calculate a good approximation of T_3 using a small computer subprogram.

- MN - This gives time when aircraft Mach number exceeds 1.0 or 2.0.

The third data set shows the time discontinuities detected during the processing of the CITS tapes from the flight. In this case, approximately 1 hour, 2 minutes, and 33 seconds of the flight were not recorded on the CITS tapes. The first interruption was most likely to have occurred during some sort of ground systems check, since it was shortly after engine startup. The second interruption was most likely to have been due to the envelometer on A/C 3. The envelometer is a device which schedules the CITS recorder to be turned off during various times in a flight without regard to what is going on or what is planned. Because of this device, CITS data went unrecorded during several MPL's and numerous other times when abnormalities were detected that did not lead to MPL's.

The examples of how these data have been used are shown in Figures 40 and 41. In Figure 40, the "cycles" refer to the PLA cycles as determined from the GE postflight processing program. The "(WB)" indicates that the YF101 engine has been retrofitted with "Warm Bridge" design HPT blades. All F101 engines had warm bridge HPT blades when they were delivered to the B-1 Flight Test Program. In Figure 41 the "R/L" refers to the time at "Red Line" or time when T_{4B} was greater than 1605° F (873.90° C). These data were also obtained from the GE postprocessing program. In both Figures 40 and 41, some engines have "estimated" values; this is because the latest flight test CITS tapes had not been processed at the time the report was issued, 7/16/79.

YF101 PLA CYCLE STATUS

S/N	CYCLES	DATE LAST EVENT	S/N	CYCLES	DATE LAST EVENT
041 (WB)	583*	7-19-79	053 (WB)	604	7-25-79
042 (WB)	512*	9-29-79	054 (WB)	499*	10-24-79
043 (WB)	538	6-12-79	055 (WB)	421	9-24-79
044	478	2-10-79	056 (WB)	590*	7-20-79
045	338	11-28-78	057 (WB)	585*	10-24-79
046	322	4-28-78	058 (WB)	490*	8-20-79
047	327	2-14-79	059 (WB)	354	3-29-79
048	376	2-14-79	060 (WB)	322	6-28-78
049 (WB)	505*	10-24-79	061 (WB)	469	4-27-79
050	234	4-12-78	062 (WB)	401*	7-25-79
051	303	5-10-78	063 (WB)	439	4-21-79
052 (WB)	429*	10-24-79	YF101 TOTAL	10119	

F101 PLA CYCLE STATUS

S/N	CYCLES	DATE LAST EVENT	S/N	CYCLES	DATE LAST EVENT
081	226	9-18-79	084	149*	10-24-79
082	248*	10-24-79	085	228*	10-24-79
083	191*	10-24-79	086	268*	10-4-79
			F101 TOTAL	1266	

*ESTIMATED

Figure 40. PLA Cycle Summary.

ENGINE	R/L	TEST CELL	A/C GROUND	A/C FLIGHT	TOTAL A/C	TOTAL
081	17.8	35.3	46.3	93.8	140.1	175.4
082	24.7*	25.9	48.5	121.4	169.9	195.8
083	17.2*	26.8	42.8	90.6	133.4	160.2
084	20.4*	16.8	39.0	80.1	119.1	135.9
085	27.9*	16.0	40.6	104.5	145.1	161.1
086	24.6*	13.9	48.3	124.4	172.7	186.6
TOTAL F	132.6	134.7	265.5	614.8	880.3	1015.0
TOTAL YF	1205.6	1133.3	2332.8	5157.6	7490.4	8623.7
TOTAL 101	1338.2	1268.0	2598.3	5772.4	8370.7	9638.7

*ESTIMATED

Figure 41. F101 Engine Operating Hours.

SECTION VI

ENGINE TRENDING

The CITS system was designed to collect trend data that were to be processed by the Ground Processing System (GPS). The development of the B-1/F101 GPS was to be a joint effort between RI, GE, and USAF/OC-ALC, but all effort was stopped on this program when the B-1 production program was cancelled. Before the cancellation, GE had completed a computer program that was to be incorporated into the GPS. This program was known as the Diagnostic and Long Term Trending (DALTT) Program.

Since the DALTT Program was still under development in the early flight test program and the need existed for GE to keep track of the relative performance level of each engine, a manual trending technique was developed using postflight ground runup data obtained from CITS. This method has proven to be a useful tool during the entire B-1 Flight Test Program.

A. TREND DATA ACQUISITION

The CITS was designed to collect up to five sets of trend data per engine during each flight. The data were to be recorded the first time all the criteria for a given "window" or set of flight conditions were met. The data set was to consist of eight slices of data (see Table 4 for parameter list) recorded over a 2-second period for any engine meeting the criteria. The original set of window requirements was revised after the program cancellation so that the data gathered would be more pertinent to the flight test program than to some long range production program. The original and revised "window" requirements are shown in Tables 11 and 12.

The CITS did not successfully record trend data until mid-1978; and then, because of several format changes in the flight test tapes, it was not until early 1979 that GE was able to reduce the data. The system did appear to work correctly, but, because of the abbreviated parameter list and the original window requirements, no real trend analysis of the data was made. Some observations made in reviewing this early data are as follows:

Table 11. Original Trend Window Requirements.

Condition	Takeoff	Climb	Cruise	Supersonic	Approach
PLA	>71°	73°-78°	57°-65°	120°-127°	25°-35°
Mach	0.22-0.23	0.5-0.75	0.67-0.72	2.0±0.01	0.2-0.25
Altitude	On Ground	14K-16K	20K-30K	50K-55K	<6.5K
Stability Time(1)	None(2)	None(2)	3 min.	3 min.	None

Table 12. Revised Trend Window Requirements.

Condition	Takeoff	Climb	Cruise	Supersonic	Postflight
PLA	>70°	73°-79°	52°-60°	120°-127°	Nf=90%±2%(3)
Mach	0.22-0.23	0.4-0.75	0.67-0.72	>1.3	<0.3
Altitude	On Ground	5K-20K	17.3K-25K	10K-25@1.3 37.5K-54K@2.2	On Ground
Stability Time(1)	None(2)	None(2)	3 min.	3 min.	80 sec

Notes:

(1) Stability time is time that conditions specified must be held prior to recording data.

(2) No stability requirement other than steady state which now takes a minimum of 12 seconds after a PLA change.

(3) Fan speed replaces PLA for this window.

- The data quality was good, same as all other CITS data.
- The window criteria worked as defined.
- Trend data acquisition was ranked as such a low priority in the CITS overall program that seldom was the full complement of eight data slices data recorded; often only one or two were recorded.

The new window criteria and expanded parameter list were introduced for Flight 4-12 and as of 10/31/79 GE was unable to completely reduce these data. It is possible to tell that the data are being recorded but nothing else can be determined until the format problems are resolved.

B. TREND DATA REDUCTION

The DALTT program was used to trend F101 engine A70-020 during the official F101 Product Verification Endurance Test. (See Section 2.7.11 of the "F101 Product Verification Test Report - F101-GE-100 Engine 470-020 Endurance Test - Volume 1 - Summary and Test Results," GE Report No. R76AEG271 for a description of this effort.) Since the completion of that test, the only use of the DALTT program has been to check it out using selected data that were manually extracted from the every-5-second flight test CITS data tapes.

No CITS acquired trend data have been reduced by the DALTT program, but it is planned to process some future data from A/C 4 when all the format changes have been resolved and a meaningfully-sized data sample has been obtained.

One of the biggest benefits that has been gained from the early effort on DALTT was the writing of the computer programs that have since been adopted to automatically plot CITS flight test data. The majority of the machine-generated plots of CITS data in this report was made using these programs. Plots generated by these programs have also played an important role in understanding the real conditions the engines were subjected to during terrain-following operation.

C. MANUAL TRENDING OF FLIGHT TEST ENGINES

The procedure developed to manually trend the flight test engines using ground runup data has been used throughout the B-1 Flight Test Program. This procedure uses data obtained at 90% fan speed as the basis for making engine-to-engine comparisons. This point, rather than intermediate or maximum augmented power, was selected for several reasons:

- To trend an engine, it is desirable to have a test point that is repeated on every flight. This is to assure that inlet conditions, operating line, and bleed/power extractions are repeatable and predictable for each set of data. The 90% fan speed point while stationary on the ground satisfies this requirement.

- Choosing maximum augmented or intermediate power for a test point increases the chance of an error when adjusting the data to a reference condition. Depending on inlet temperature (T_1) and turbine blade temperature (T_{4B}) variations, fan speed can be rolled back as much as 200 rpm from the new engine fan speed schedule. Using 90% fan speed minimizes this adjustment error.

- GEEFTC test stand data show that most YF101 engines maximum augmented thrust lies within a 2% band, as shown in Figure 42. Variables such as augmentor efficiency, augmentor fuel schedule, and engine operating line have a small influence on max augmented thrust relative to the effect of fan speed roll back. Thus, ranking engines at 90% fan speed using T_{4B} gives a reasonable prediction of max augmented thrust, since the relationship between fan speed roll back and T_{4B} level is known.

The engine trending calculation procedure is shown in Figure 43. A typical trend plot generated from this procedure is shown in Figure 44. The open symbols are postflight runup data; the solid symbols are test strand data. The initial offset between a test stand run and the first postflight data point that follows it can be attributed to installation effects. At 210 hours, Engine 470-049 had its CDP seal changed and had warm bridge turbine blades installed. The restoration of engine performance can be readily seen in the plot. The data scatter is caused by several factors:

- Fuel flow measurement accuracy/repeatability

- Variation in installation effects, primarily caused by uncertainty is bleed split between the four engines

AD-A086 130 GENERAL ELECTRIC CO CINCINNATI OH AIRCRAFT ENGINE GROUP F/G 21/5
F101 CENTRAL INTEGRATED TEST SUBSYSTEM EVALUATION.(U)
FEB 80 C T VINCENT, C A ARULF F33615-79-C-2022
UNCLASSIFIED R79AEG622 AFWAL-TR-80-2002 NL

2 OF 2
AD
A086130

END
DATE
FILMED
8-80
DTIC

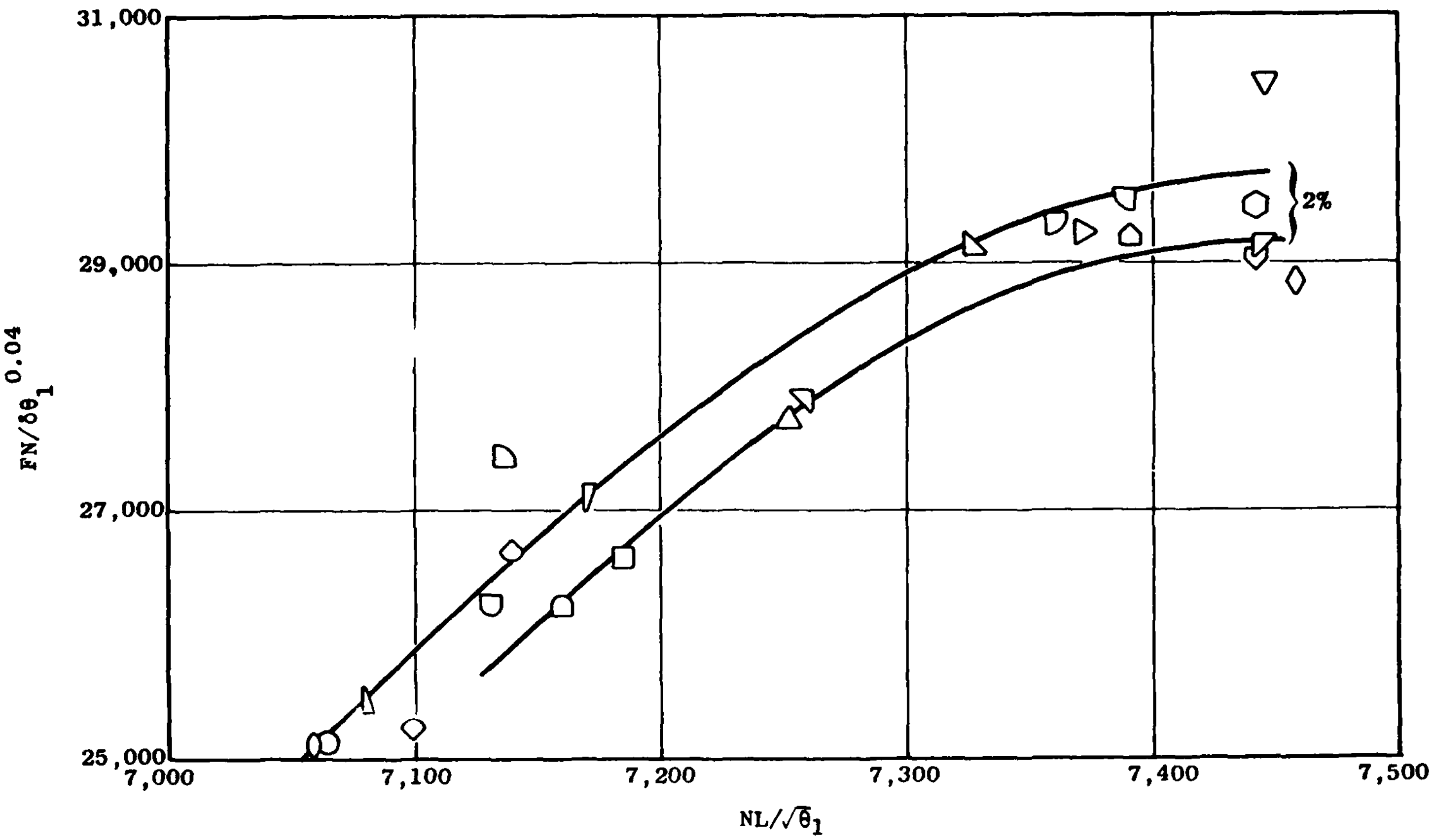


Figure 42. YF101 Test Cell Data Maximum Augmented.

1 PTO from Alt chart, if no Ref. 3

2 $\theta_1 = (T1 + 460)/519$

3 $NF/\sqrt{\theta_1}$ = % NF X 75.7 $\div \sqrt{\theta_1}$

4 $T4B^{\circ}R = T4B^{\circ}C \times 1.8 + 492$

5 From $NF/\sqrt{\theta}$ vs ηR curve

6 $\delta 1$ = PTO x $\eta R/14.696$ or Ref 3 x $\eta R/14.696$

7 $= T4B/\theta^{.905} + .285 (6800 - NF/\sqrt{\theta_1})$

8 $= Wf36/\delta_1\theta_1^{.688} + 4.3 (6800 - NF/\sqrt{\theta_1})$

									1	2				3	4		5	6		7	8
Flt	S/N	Hrs	%NF	T4B °C	WF36 #/Hr	T1 °F	Ref 3 Psia	Alt Ft	PTO PSIA	θ_1	$\sqrt{\theta_1}$	$\theta_1^{.905}$	$\theta_1^{.688}$	$\frac{NF}{\sqrt{\theta_1}}$	T4B °R	$\frac{T4B}{\theta^{.905}}$	ηR	$\delta 1$	$\frac{W_f36}{\delta_1\,\theta^{.688}}$	$T4B/\theta^{.905}$ @ 6800NF	$Wf36/\delta 1\ \theta^{.688}$ @ 6800Nf

Figure 43. Postflight Performance Calculation Procedure.

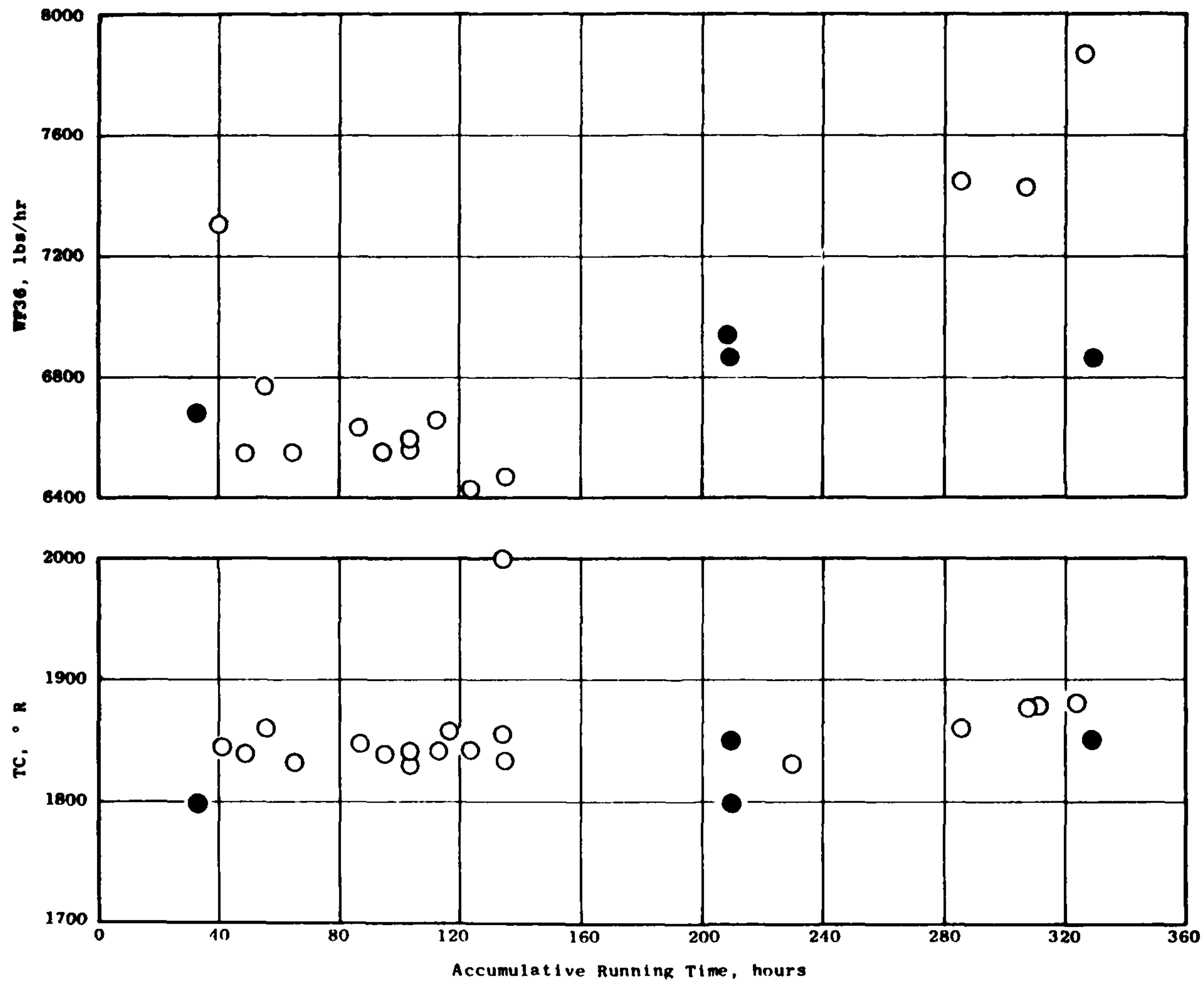


Figure 44. YF101 Flight Engines Adjusted to 6800 NF/$\sqrt{\theta}$, Engine S/N 470-049.

- Use of a single data slice from every-5-second data instead of a median or average of the eight data slices that should be available when recently acquired trend data from A/C 4 is reducible

The large gaps in the later data show that, as the program progressed in time and confidence in the engine increased, the pilots found less and less time to perform the ground runups. This points out that the technique used here is quite satisfactory for the initial flight test program; but that in a production program, the trend point must be selected such that the data are acquired during each flight at a point that is always repeated, such as the takeoff or climbout.

D. LONG RANGE TRENDING REQUIREMENTS

Based on the trending of the official PV endurance engine using the DALTT Program, the CITS trend data requirements were expanded to give the present parameter list, shown in Table 4. With these parameters, it is felt that a satisfactory long term trending program could be developed using DALTT as a starting point. To enhance the effectiveness of the trend program, several parameters could be added to the engine/aircraft so that gas path analysis could be better performed. Compressor discharge temperature (T_3) would be the engine parameter with the highest payoff, and some indication of actual bleed flow would be the aircraft parameter of highest importance. With the exception of the aircraft fuel flow measurement, all parameters have exhibited adequate accuracy during the B-1 Flight Test Program.

In a production program, the number of windows could be reduced, especially with the change in aircraft mission that minimized or eliminated supersonic flight to just two windows - takeoff and climb. In a flight test program, the 90% ground run point should be retained.

SECTION VII

MAINTENANCE ACTIONS AS A RESULT OF CITS

The payoff of the CITS was to have been its ability to specify the maintenance action, if any, that should be taken after each flight. The CITS was to detect incipient failures as well as faults leading to MPL and was designed to support the two-level "On Condition" maintenance concept that was planned for the B-1 production program. "On Condition" maintenance is based on determining the condition of an engine while it is on the wing and performing maintenance only when it is required. This is in contrast to the practice of performing phased or insochronal inspections (requiring shop visits) based on operating or calendar times. The recommended installed engine inspections for the YF101 and F101 engines can be found in their respective Operation and Service Manuals, GEK 35617 and GEK 43499.

A. MAINTENANCE ACTIONS AS A RESULT OF CITS DETECTIONS

CITS responses to the MPL events were discussed in Section III-B. This section, on the other hand, is devoted to a sample of the incipient failure-type detections made by the CITS during the B-1 Flight Test Program. While the samples discussed are not the only ones available, they represent the types of failure CITS was to detect in support of the "On Condition" maintenance concept. Many of the types of problems discussed in this section were first encountered in ground runs where CITS data were not usually recorded. A common example of this type of problem is the start stall, or hung start, which the CITS, had it been operational, would normally have detected as either a "T_{4B} Hi" or a "Slow-No Start." Isolation, if any, would have been to the MEC, which would be correct; since in more than 95% of such cases, the program was corrected by making either a specific gravity or P_{S3} bias adjustment to the MEC.

1. Flight 3-9 - "IGV's Off Schedule"

CITS detected that the IGV's were off schedule on Engine 3; the CITS fault data confirmed the problem. Isolation was to the basic engine. The AFTC was replaced and the problem was corrected. Teardown inspection revealed a bad IGV module in the AFTC.

2. Flights 3-30 and 3-31 - "IGV's Off Schedule"

CITS detected that the IGV's were off schedule on Engine 3, and the CITS fault data confirmed their operation to be intermittent. Isolation was to the basic engine in Flight 3-30 and AFTC in Flight 3-31. The AFTC was replaced and the problem was corrected. Teardown inspection revealed a bad IGV module in the AFTC.

3. A/C 2 Ground Run 10/20/77 - "IGV's Off Schedule"

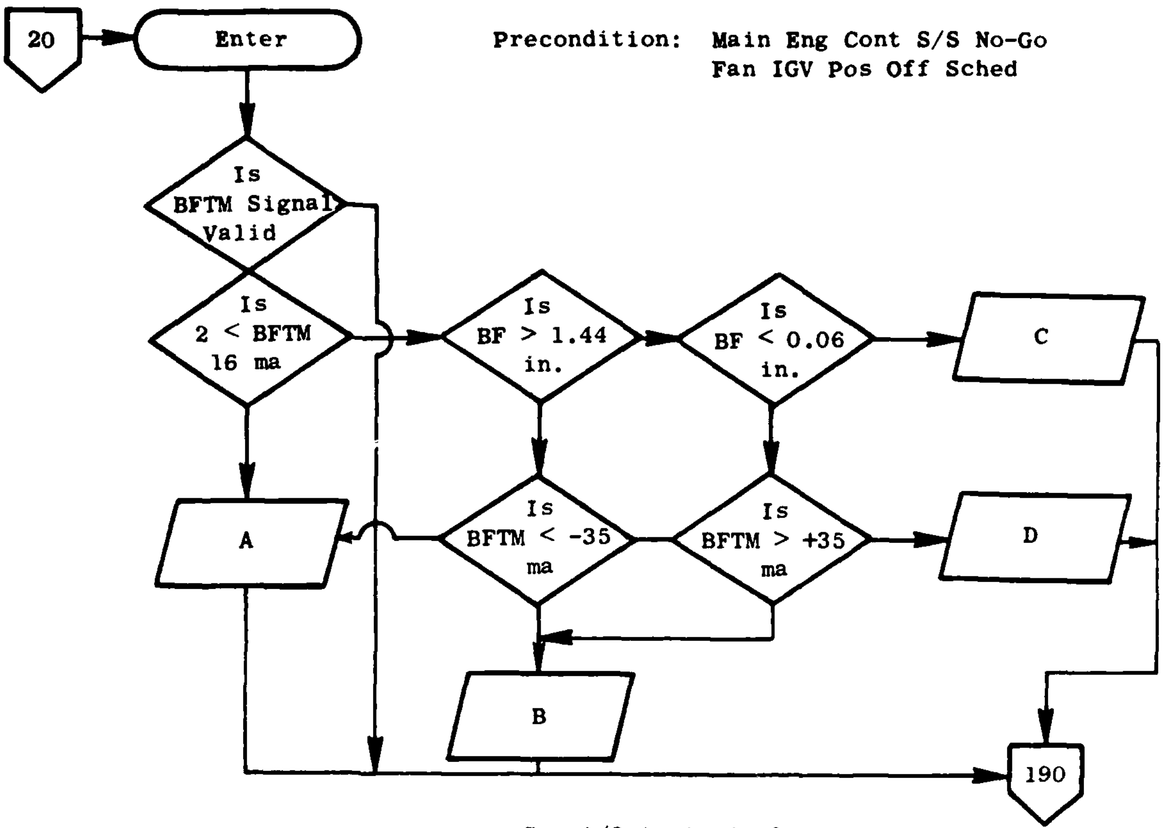
CITS detected that the IGV's were off schedule on Engine 4 during ground run. The CITS message was ignored by everyone, but GE Technical Representatives picked up the problem from CITS data obtained from the CCD parameter monitor. CITS correctly isolated to the IGV servo/actuator. CITS isolation was ignored by all, and the AFTC was changed. But the problem persisted on the second ground run, with CITS correctly isolating to the basic engine due to further actuator degradation. Isolation was once more ignored by all, and this time the engine electrical wiring harness was changed. But the problem remained on the third ground run. The Technical Representative changed the IGV servo/actuator as a last measure. The problem was finally corrected by replacing the LRU originally isolated by CITS. See Figure 45 for CITS isolation logic for this fault.

4. Flight 3-43 "Low Lube Level"

CITS detected a "Low Lube Level" condition in Engine 4 as the aircraft was returning to Edwards AFB at the end of the flight. The isoltion was for the basic engine. Postflight inspection revealed several loose fittings which were subsequently tightened. When a ground run was made, fresh oil continued to be evident in the fan duct. The engine was removed from the aircraft and sent to the local GE shop for teardown inspection. The inspection revealed that a crack in the 6 o'clock fan frame strut was letting the lube oil escape into the fan flowpath.

B. MAINTENANCE ACTIONS BASED ON CITS ACQUIRED DATA

There were five basic types of maintenance action taken as a result of data obtained by CITS. All but one of these types were based on the data



Input/Output Display

I.D. No.	L Legend	M_1 Display	M_2 Display	I_m WUC Display	R
A	None	None	-	AFTC	-
B	None	None	-	IGV Servo Valve/Actuator	-
C	None	None	-	Basic Engine	-
D	None	None	-	AFTC	-

Figure 45. Ground and In-flight Fault Isolation.

obtained by postflight processing of the CITS flight test data tapes as discussed in Sections V-C and VII-C. The last type was based on CITS data obtained from the CCD parameter monitor during engine troubleshooting.

1. Insert-Type High Pressure Turbine Blades

Based on factory testing, it became apparent early in the B-1 Flight Test Program that the insert-type high pressure turbine blades used in the YF101 engines had serious life-limiting problems. As a result, their use would have to be closely monitored to avoid any in-flight failures. The factory test data showed that there was a correlation between time at rated temperature and the failures. Using these data, limits were set to replace the blades upon reaching either of two sets of conditions: (1) when 60 hours had been accumulated on an engine whose blades were all running at the same temperature ±5° F (based on pyrometer photos), and (2) when 36 hours had been accumulated on an engine where blades had a temperature range of up to ±20° F from the average. The time-at-rated-temperature data were obtained by postflight processing of the CITS flight test data tapes that were used to track engines. When an engine would reach its rated temperature time limit or was expected to do so in the next flight, it was removed from the aircraft to have its turbine blades replaced. This method, together with postflight borescope inspections, prevented any YF101 flight test engine from having an HPT blade failure. While some blades had insert failures which caused secondary damage to the turbine shrouds, there were no blade airfoil separations. The insert-type HPT blades were replaced on 16 of the 23 YF101 engines; the remaining 7 engines were set aside after the introduction of the 6 F101 flight test engines.

2. HPT Forward and Aft Blade Retainers

Factory testing also revealed an LCF-type failure mode on the forward and aft HPT blade retainers. This failure could be expected whenever the idle-to-intermediate-to-idle cycle (PLA cycle) count reached 425 cycles. Once again the data obtained from the postflight processing of the CITS flight test data tapes were used to track engine and blade retainer PLA cycle counts. Numerous engines have been scheduled through the shop to have their blade retainers either replaced or reworked to a configuration that eliminates the failure mode, based on their PLA cycle count histories. Aside from small cracks, which were discovered in the shop during the rework/replacement cycle, there have been no failures to either of these blade retainers in the B-1 Flight Test Program.

3. Low Pressure Turbine Spacer

A problem similar to that identified for the HPT blade retainers was identified for the LPT spacer as well. This problem is also PLA cycle-dependent but the limit is at a much higher value - 900 PLA cycles. Although no engine has accumulated this many cycles, two engines with over 500 PLA cycles were inspected as a precaution; no faults (cracks) were found. As the engines continue to age and this limit is approached, they will be scheduled through the shop for the required maintenance action.

4. Performance Restoration

Engines have been replaced on the aircraft in accordance with their performance ranking as determined from CITS data obtained during the postflight runups to 90% fan speed. (See Sections IV-A and VI-C for discussions of ranking and trending procedures.) Not all engine changes based on this ranking technique resulted in a shop visit for the removed engine; sometimes it was desirable to have a slightly better engine installed to attempt to meet the aircraft thrust requirements during the air loads and high supersonic testing programs. Some performance removals have been made so that the engines could have their performance restored (thrust and temperature margin - not sfc) by replacing selected performance-determining components. In a production program, such a technique could be used to schedule engines through the shop when their performance trends indicated they were approaching the minimum acceptable standard for an operating fleet aircraft.

5. Engine Troubleshooting

CITS data obtained from the CCD parameter monitor and from the failure snapshots were invaluable for troubleshooting the engine problems. Many of events discussed elsewhere in this report were verified during ground runs, where the only data normally available is from the CCD parameter monitor. After faults were corrected, ground runs were made in order to substantiate the success or failure of the component replacement/adjustment. Once again, the only data source was the CCD parameter monitor. Without this source of data, many of the engines would have required removal from the aircraft so they could be run in a test cell where data could be obtained to verify the fault/fault correction.

SECTION VIII

SENSOR SELECTION

When the F101 engine design was modified to be compatible with CITS, the impact was minimal. Only three sensors were added to the existing engine design plus the CITS processor (CITSP). The three new sensors, all pressure transducers, were incorporated into the CITSP, where a more favorable environment existed due to the shock-reducing mounting and fuel cooling than would be available anywhere else on the engine exterior (excluding AFTC which has the same mounting and fuel cooling). The pressure transducers that were added were the strain gage diaphragm type and they measured:

- Compressor Discharge Static Pressure - P_{S3}
- Compressor Inlet Total Pressure - P_{T25}
- Augmentor Fuel Pressure - PWFR

The CITSP scaled and converted the already available AFTC parameters to serial digital format so they would be available to the Data Acquisition Unit for use by the CITS. A complete listing of the engine parameters available in CITS is shown in Tables 1 and 2.

Three of these signals came from sensors provided by the aircraft. They are:

- Fan Inlet Total Pressure - P_{T2}
- Core Fuel Flow - CFF
- Aircraft total Fuel Flow - AFF

Additionally, the aircraft supplied excitation and signal conditioning to the P_{T25} transducer mounted in the CITSP. The augmentor fuel flow (FF) is determined by subtracting the core fuel flow from the aircraft total fuel flow.

A. SENSORS/SIGNALS WITH LOW PAYOFF

The PWFR signal is used only by the CITS; all other parameters (except self-test check words) have at least two uses in the aircraft/engine. This parameter was added to help meet the fault isolation goals of the overall CITS engine test. This parameter could be eliminated with little effect on isolation ability if the isolation were done by a larger capacity ground computer in lieu of the in-flight CITS computer.

The fan speed signal from the CITS processor could be eliminated on all future engines, since the aircraft fan speed signal has proven to be very reliable and much more accurate (0.3% versus 2.5%). CITS is presently not using the fan speed signal from the CITSP.

B. SENSORS/SIGNALS FOR FUTURE CONSIDERATION

The sensor having the greatest potential for future consideration is the core engine variable stator vane (VSV) position. This parameter would be very useful in troubleshooting, incipient fault detection and isolation, and making engine performance/operability determinations. Closely coupled with this sensor is the core engine inlet temperature (T_{25}). Although a T_{25} can be calculated from fan speed and inlet temperature, a measured value would be preferred to maximize the usefulnes of the VSV position signal.

The third additional parameter that should be considered is the compressor discharge temperature (T_3). This parameter would be required if gas-path, module performance trending were to be included in a future engine's long range ground trending program. T_3 would also be very useful in a flight test program for allowing a more comprehensive performance ranking of the limited number of flight test engines.

C. SENSOR ACCURACY

The accuracy of the B-1/F101 CITS sensors was fully discussed in Arnold Engineering Development Center Report No. AEDC-TR-78-41, "Central Integrated Test Subsystem (CITS) Sensor Evaluation on the F101-GE-100 Turbofan Engine During Product Verification Testing at the AEDC," dated October 1978. The comparisons made in this report, however, are only between the production-type CITS sensors and development quality "truth instrumentation"; they do not take into account how the data are used, except for calculating in-flight thrust, or the fact that many of the sensors had been engine control system sensors before they were CITS sensors.

General Electric observation is that the data quality and sensor accuracy have been excellent for the purposes of CITS and for a general flight test evaluation of the engines. On specific performance-oriented flights, the special Level 14 aero instrumented engines were installed to obtain the required data for a comprehensive performance assessment of the engines to be made. Another observation is that the repeatability of the sensors has been excellent over the life of the program. There have been few failures and most of those either were designed out of the F101 engine sensors or posed quality problems in the first place. The one exception has been the aircraft fuel flow measurements, both core and total. These parameters have always yielded a somewhat unstable output, and averaging must be used to make any meaningful calculations using these data.

Because of inlet distortions and operating line effects, there may be fairly large offsets in the P_{T2} and T_{T25} absolute aero values compared to the average determined by aero instrument rakes. But these offsets need not render the data useless, for the single sensor measurements are repeatable and predictable for any given set of flight conditions where correlation data have been obtained. This implies that it is not the sensor itself that is causing the inaccurate measurement but rather, the location of the probes.

D. SENSOR RELIABILITY

Sensor reliability has been excellent. Through July 1979, there have been only seven CITS inputting engine sensor failures in the YF101/F101 flight test program. This number does not include removals during "shotgun" troubleshooting or sensors removed because of handling damage, convenience, or quality control errors. The seven documented failures were as follows:

- **Two T_2 sensors had been made using the wrong wire material. They had been redesigned for the F101 and shock mounts have been added to all YF101 and F101 engines.**
- **Two sensors that were monitoring oil tank level were damaged by overtemperature during gulping incidents. These failures are being investigated, and the F101 DFE sensor has been ruggedized.**
- **Two PWFR transducers in the CITSP had failed to have their protective orifices reinstalled during maintenance.**

- A P_{T25} transducer in the CITSP had been manufactured defectively.

In addition to these failures, there were two other CITSP failures, one for a defective amplifier in the powerup circuit and the other for an internal fuel leak that was traced to a loose fitting.

SECTION IX

DATA SAMPLING RATE

The CITS sampling rate is four times per second for each engine's parameters. Likewise, the complete CITS engine test is completed on each engine four times per second. This sampling rate appears to be adequate for fault detection and isolation purposes. Data recorded at 4/sec and 16/sec rates during Flight 2-59 when Engine 1 (470-081) experienced a stall were compared to see the effect on CITS detection/isolation of that event.

While the 12/min. or every-five-seconds rate used by the flight test CITS data recorder has been satisfactory for most parameters, a higher rate would be desirable for several key engine usage parameters.

A. FLIGHT 2-59 ENGINE STALL EVENT

This event was caused by augmentor instability induced by improper piloting on the inner ring flameholder gutter. This resulted in the partial flameout-relights that caused the parameter cyling prior to the stall (Figure 46). All parameters plotted in Figure 46 are 4/sec data except for P_{S3} which used 16/sec data. Figure 47 shows a comparison of the 16/sec data (thin line) and the 4/sec data (heavy line) seen by CITS. As can readily be seen, the 4/sec data lose little of the detail of the event. The 4/sec data do lose 19-20 psi of max.-to-min. peak for this particular event; but if the CITS data had been offset 1/8 sec, it would not have missed anything.

If the CITS engine test had been operating at 16/sec instead of 4/sec, the results would have been the same - no CITS output. The only limit that was exceeded during this stall/recovery sequence was the minimum P_3 limit of 35 psia. Since this limit was not exceeded for three consecutive tests, CITS should not have outputted a fault detection message. Note that a "Low Power Loss" would not have been detected, since total core speed drop was less than 3% for the entire event and the limit is a drop of 5% in 0.5 second.

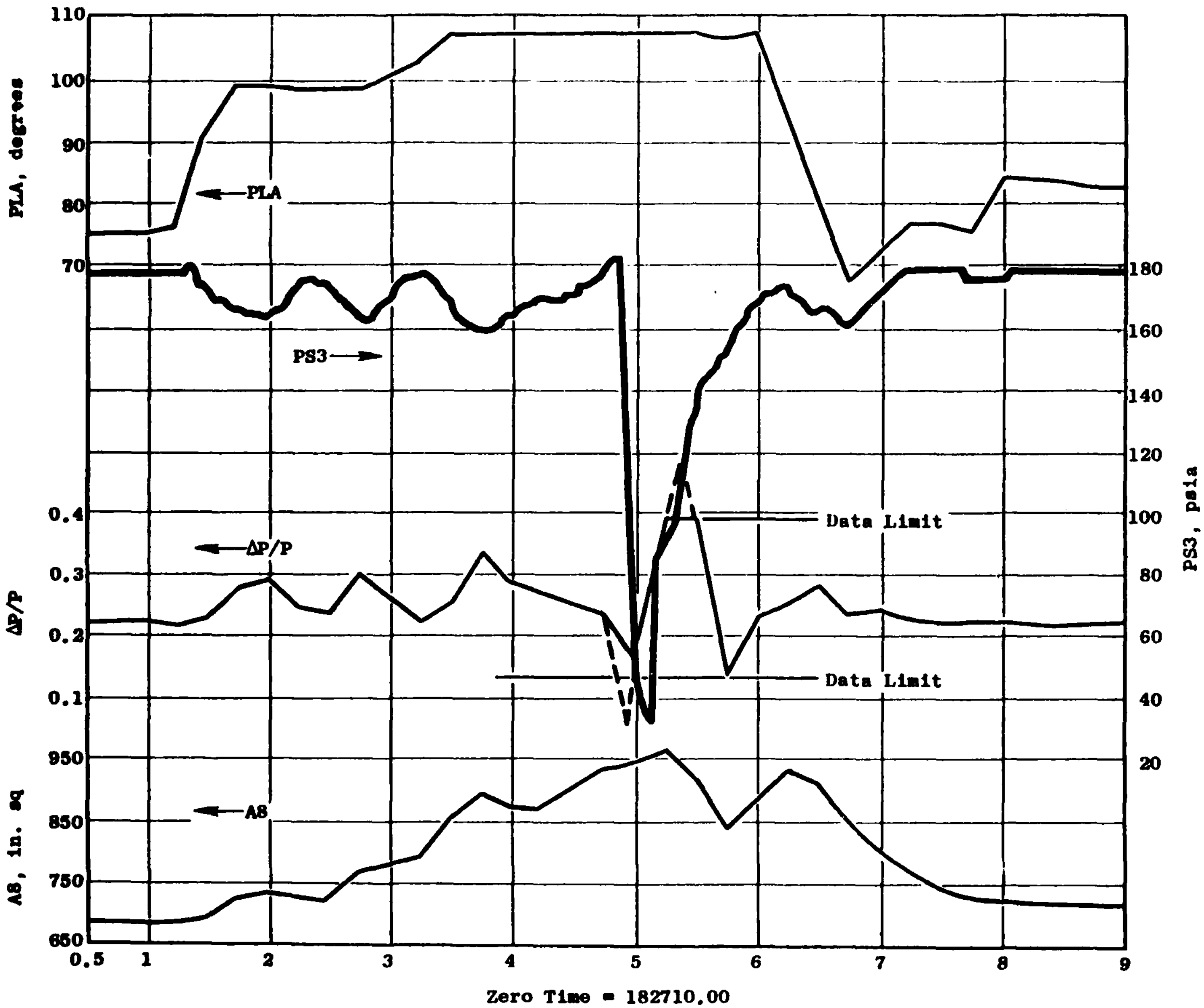


Figure 46. Flight 2-59 Engine Stall 470-081.

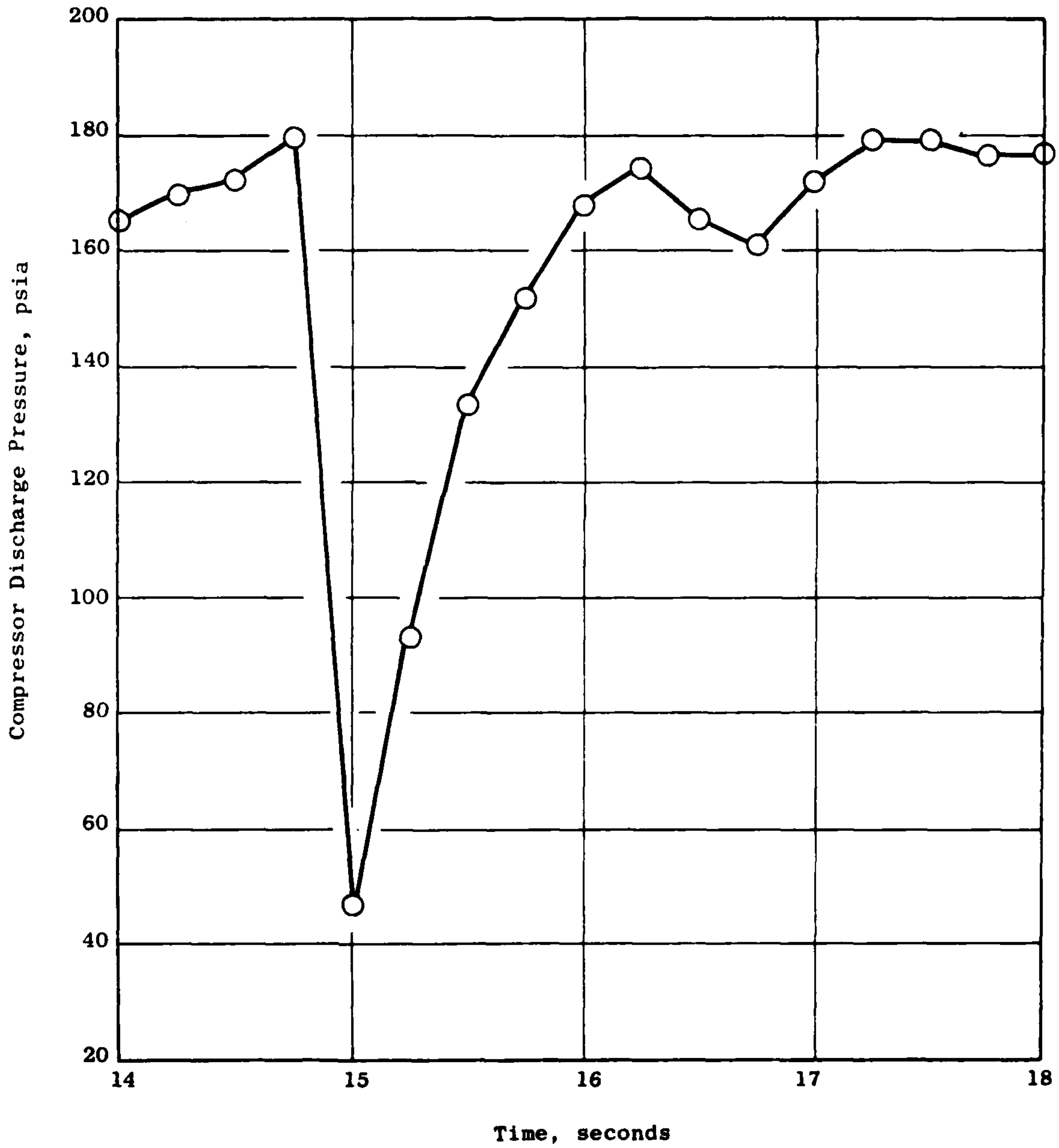


Figure 47. Flight 2-59, Engine 470-081 Stall Event.

B. FLIGHT 3-47 ENGINE STALL EVENT

This event is described in Section IV-B.10 in detail but is included here to determine if the data sampling rate would have affected the CITS response to this event. A plot of the 4/sec data seen by CITS is shown in Figure 48. CITS did not detect a "Stall," "T_{4B} Hi," or "Low Power Loss" during this event. Neither T_{4B} nor P_{S3} was out of limits for the required three consecutive readings, so CITS was correct in not indicating either of these faults and the data sampling rate would not have affected the CITS performance. The "Low Power Loss" would be affected by a less frequent sampling rate.

Analysis of the 4/sec data shows that the maximum decel rate that the CITS could have determined is between 3.26% and 4.02%, the limit being 5% in 0.5 second. The test requires three data slices (totalling 0.75 second) to complete; then, after a 1-second interval, it starts over on the next data slice. Since there is no way of knowing the data slice on which the CITS logic will begin the test, the range of possible rates is given. If the same logic is used with an appropriate change in limits to match the data sampling rate, other sampling rates can be evaluated. For a 2/sec rate, the range elevates to between 4.75% and 7.27% against a limit of 10% in 1 second. For a 1/sec rate the range is defined by 8.05% and 11.47% against a limit of 20% in 2 seconds. On a percent-of-limits basis, these ranges are expressed as follows:

Sampling Rate	Range ~% of Limit
4/sec	65.2 - 80.4
2/sec	47.5 - 72.8
1/sec	40.3 - 57.4

The data from this event lead to several conclusions:

- The limit is incorrect. It should be adjusted down to 3% in 0.5 second. The original limit of 5% in 0.5 second was based on SLS stalls carried out in the factory test program. Subsequent testing at AEDC shows that this limit must be reduced for altitude conditions since core speed decel rate decreases at altitude.

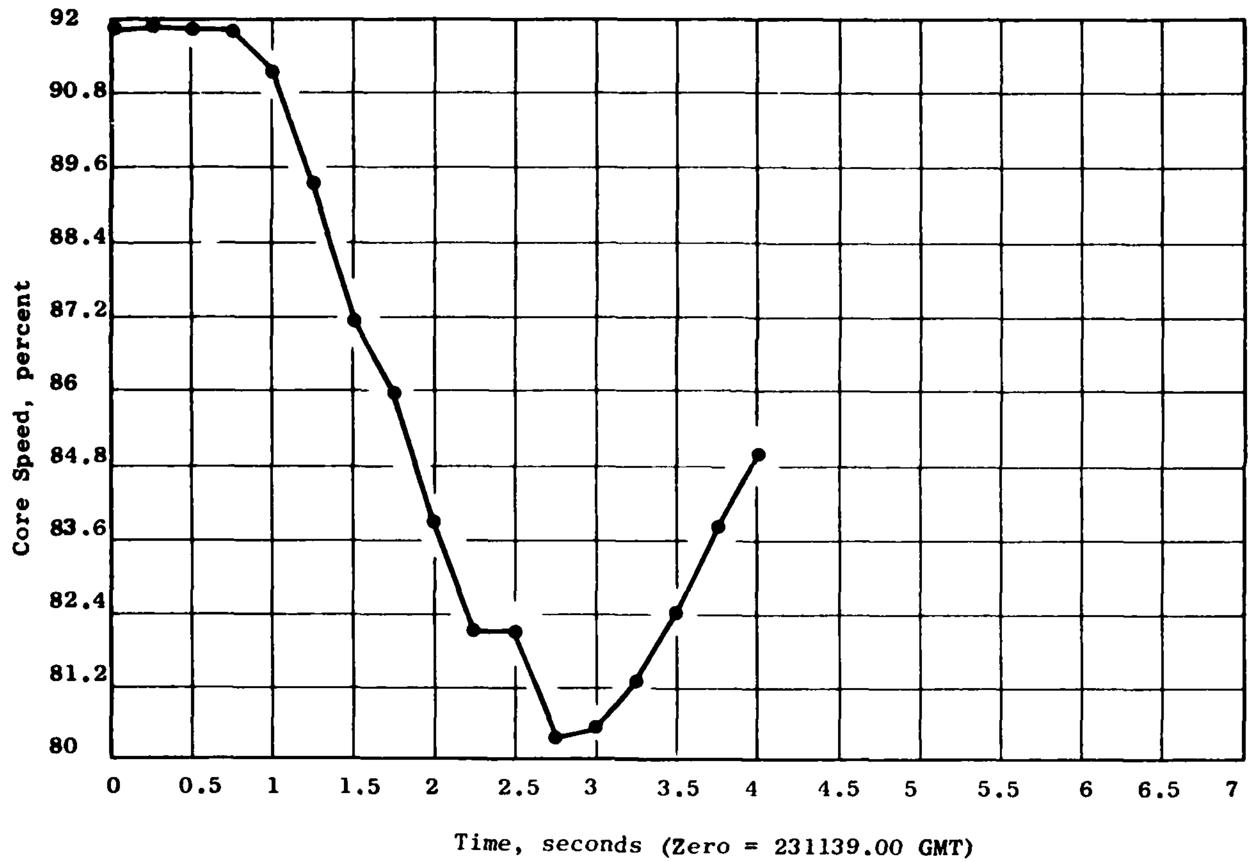


Figure 48. Flight 3-47 E2 Stall Event - 4/Sec Data.

- Less frequent sampling rates limit the core speed's ability to serve as the parameter to test for determining a "Low Power Loss" since sensitivity decreases as sampling rate decreases.

- The decel rate in a stall is at its maximum in the first 1 to 1-1/2 seconds; so even if the engine had not recovered and had continued to decel, the CITS would not have detected a "Low Power Loss" based on this core speed test.

- A more frequent sampling rate would in all likelihood be more sensitive. But it is imprudent to change the CITS rate for just one test when the existing rate appears to be adequate provided that the correct limit is used.

SECTION X

ENGINE USAGE TRACKING

One of the truly unexpected benefits of the CITS has been the engine usage tracking data that were extracted from the CITS flight test data tapes (every-5-seconds data). The importance of engine usage tracking is becoming more important each year as analytical techniques are developed to reduce these data into a set of measurements that can be related to engine life and maintainance requirements.

The direct benefits of these data relative to the B-1 maintenance program were previously discussed in Sections VII-B.1 through VII-B.3. There have been other benefits, not only to the B-1/F101 program, which have resulted in reevaluating the differences between actual engine usage and the "design mission" usage that was the basis for engine design.

A. B-1 ACTUAL ENGINE USAGE

The CITS flight test data tapes were reduced and profile plots were made of the key engine usage parameters versus time for entire flights of the B-1. This set of data immediately revealed that there were more full (idle to intermediate or above and back to idle) engine transients or PLA cycles than originally designed for the F101 engine. The YF101/F101 engine was designed to fly the mission mix of the six types of mission specified in the B-1/F101 program RFP. Composite results of these missions revealed that the key engine usage parameters have the following values based on a 4000-hour hot-section life:

PLA Cycles - 2 cycles per mission

Time @ Rates T_{4B} - 21.15 minutes per mission

Average Mission Length - 5.0 hours

Review of the usage data extracted from the CITS flight test data tapes yields the following actual experience to data:

PLA Cycles - 10.88 cycles per flight

Time @ Rated T_{4B} - 75.57 minutes per flight

Average Mission Length - 5.43 hours

These numbers have ground cycles and ground rated T_{4B} time included, but they have not been adjusted upward to account for the many data gaps caused by the envelometer on A/C 3 and 4. On balance, then, they are most likely quite representative of the real YF101/F101 engine usage in the B-1.

Because of a similar analysis done in early 1978, the F101 Accelerated Mission Test (AMT I) was updated to incorporate this flight test experience into the factory test program. This effort yielded AMT III.

Accelerated Mission Test III (AMT III)

This test was developed to represent the proposed SAC training mission which was to replace the six-mission mix as the intended use of the B-1. This training mission was to include 40 minutes of "auto throttle" terrain-following and 60 minutes of "manual throttle" terrain-following in each flight. Review of flight profiles indicated that there was a high cyclic content in both the manual and auto terrain-following activities but that the cycle size was small in the auto terrain-following and large in the manual terrain-following activities. Figures 49 and 50 show typical profiles of auto and manual terrain-following runs.

Using this set of data, the AMT III was designed and adopted for use as a factory test to accrue mission-oriented endurance time on F101 engines. Figure 51 shows the AMT III definition.

B. USAGE TRACKING DATA MADE AVAILABLE TO OTHER PROGRAMS

The YF101/B-1 CITS flight test data tapes were made available to other USAF-funded study programs. The primary user of this set of data was the "High Through Flow Turbine Program" (HTFT), Contract No. F33615-78-C-2007. The HTFT program reduced a large quantity of CITS data in support of the Phase I mission analysis effort. In this program, the flight profiles of many flights were examined, and selected mission "legs" that corresponded to those in the SAC training mission were selected for mission leg severity impact studies using the Operational Severity Analysis (OPSEV) computer program. The individual legs were then spliced together to form a sample of composite SAC training missions. The range of severity for these composite missions showed that the

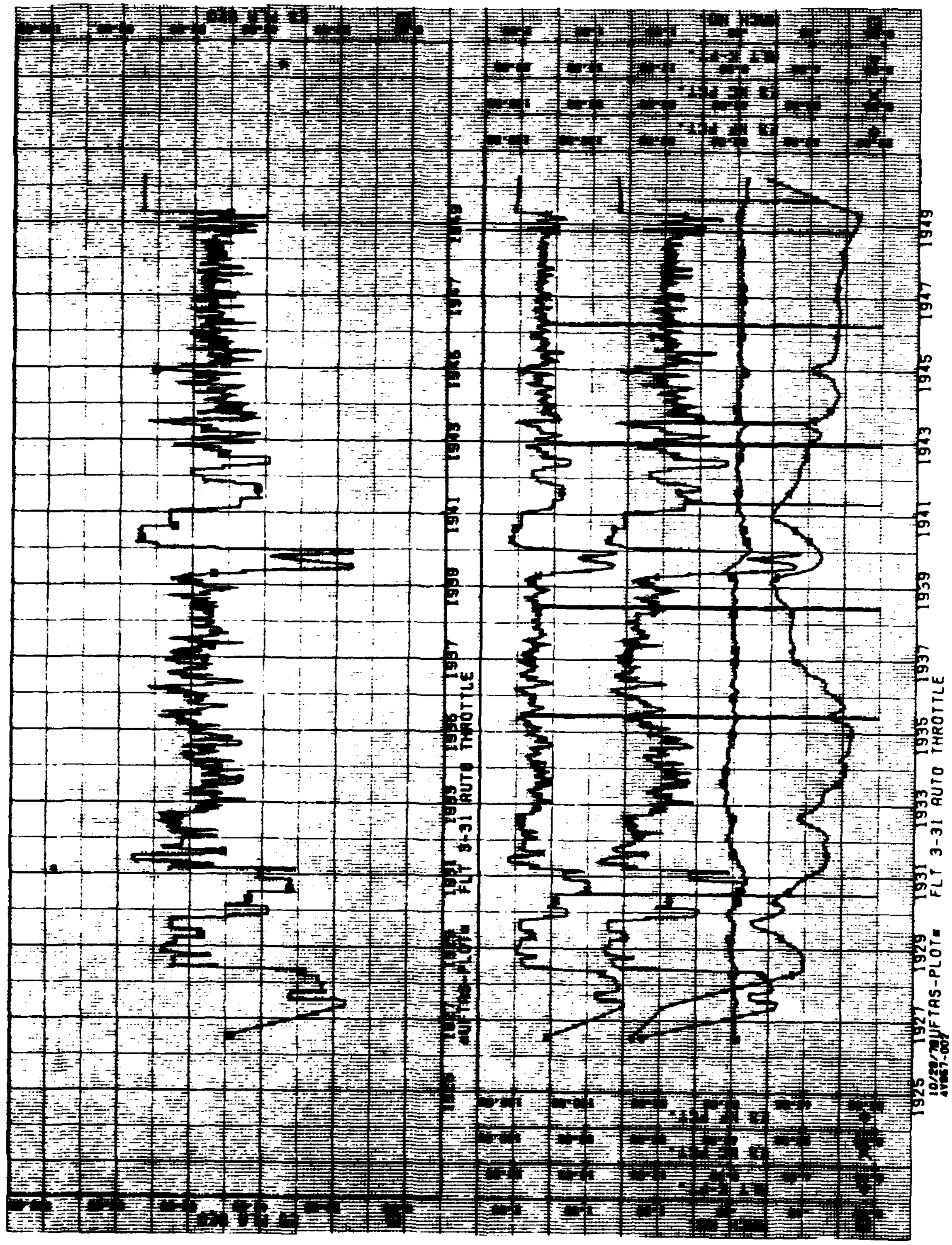


Figure 49. Flight 3-31 Auto Throttle.

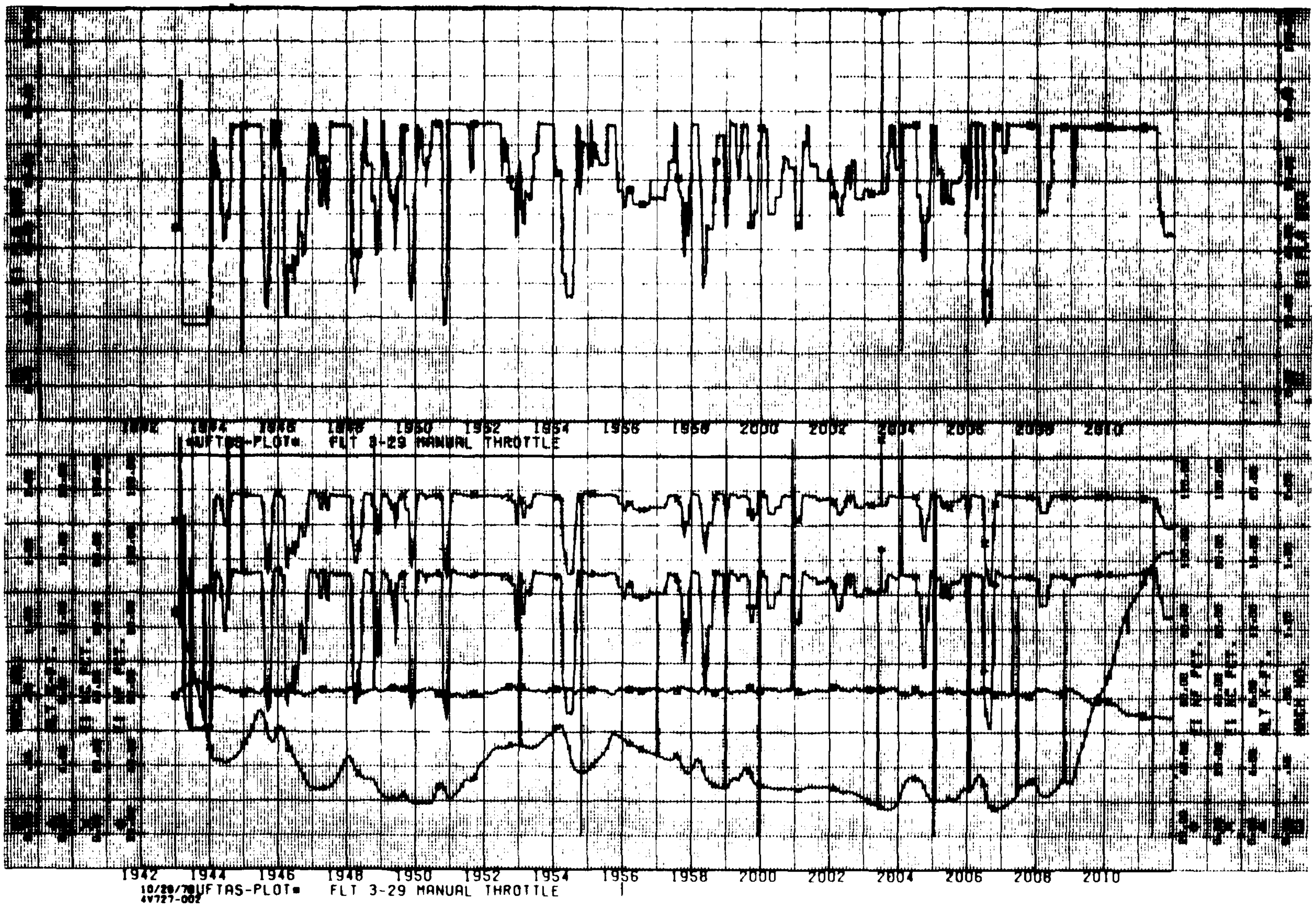


Figure 50. Flight 3-29 Manual Throttle.

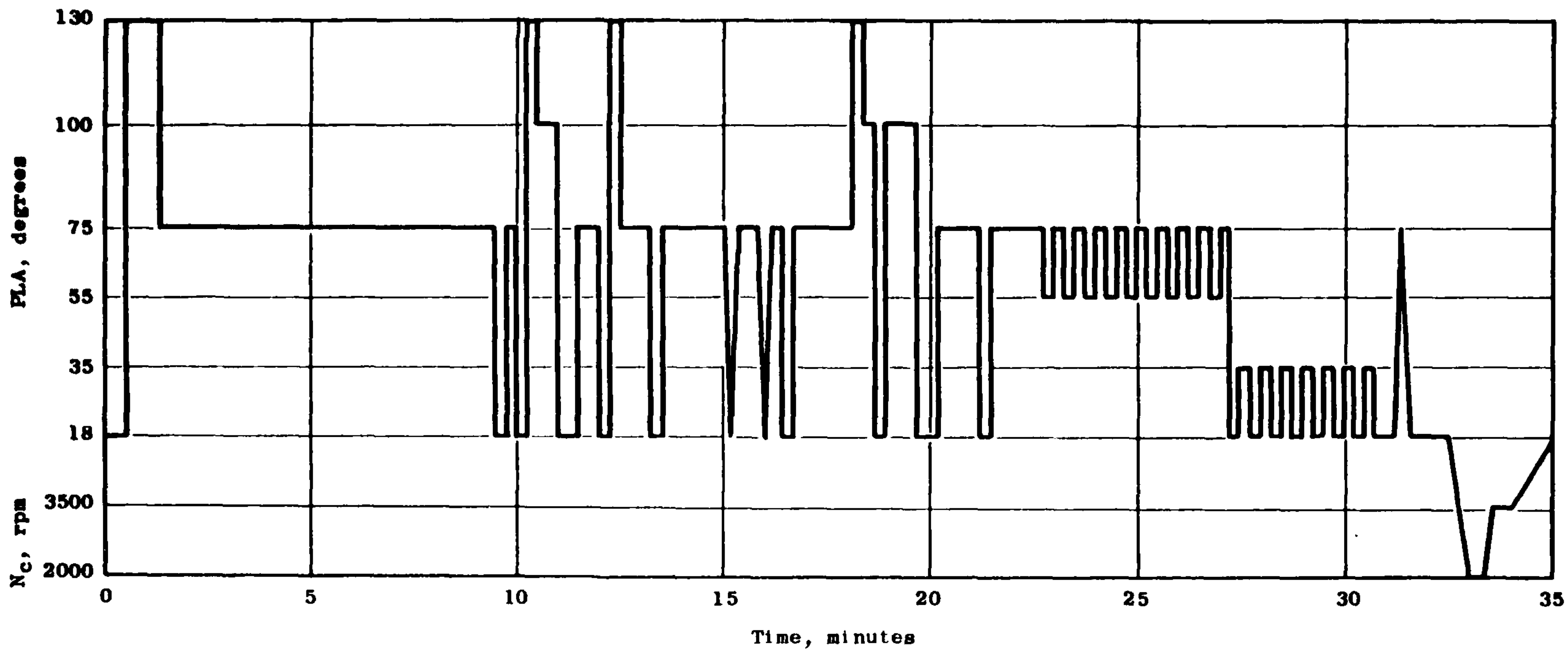


Figure 51. Accelerated Mission Test III.

intended use of the B-1/F101 in the SAC training mission was 1.3 to 4.3 times more severe than the missions the engine was designed to fly. Without the CITS test data tapes, this phase of the HTFT program could not have been completed with the same degree of thoroughness.

C. ENGINE USAGE PARAMETERS/SAMPLING RATE

Working from the B-1 flight test experience, six engine usage parameters have been identified that should be incorporated into a future CITS software module or into any future engine usage tracking system. They are:

- Time
- Mach Number
- Altitude
- Power Lever Angle
- Turbine Temperature
- Inlet Temperature

With these parameters a very good understanding of an engine's real usage can be determined. To be effective as usage tracking parameters, however, they must be recorded continuously and frequently so that a true flight profile is available. In the B-1 program, the every-5-seconds rate for the CITS flight test data tapes was determined for reasons other than just engine usage tracking, since the tapes contain data from all 29 subsystems monitored by CITS. In a pure engine usage tracking system, the ideal data sampling rate would be one sample per second for the six parameters specified above.

Figure 52 shows a sample of 1/sec PLA versus time data (small triangular symbols and dashed lines) for some typical engine operation. Also shown (large circular symbols and solid lines) are the data that would have been recorded if the data sampling rate had been once every 5 seconds. Analysis of the two data rates shows the superiority of the 1/sec rate, as summarized below:

- The actual number of PLA cycles per data slice is 4. The every-5-seconds would record as 2, giving a 50% error rate.

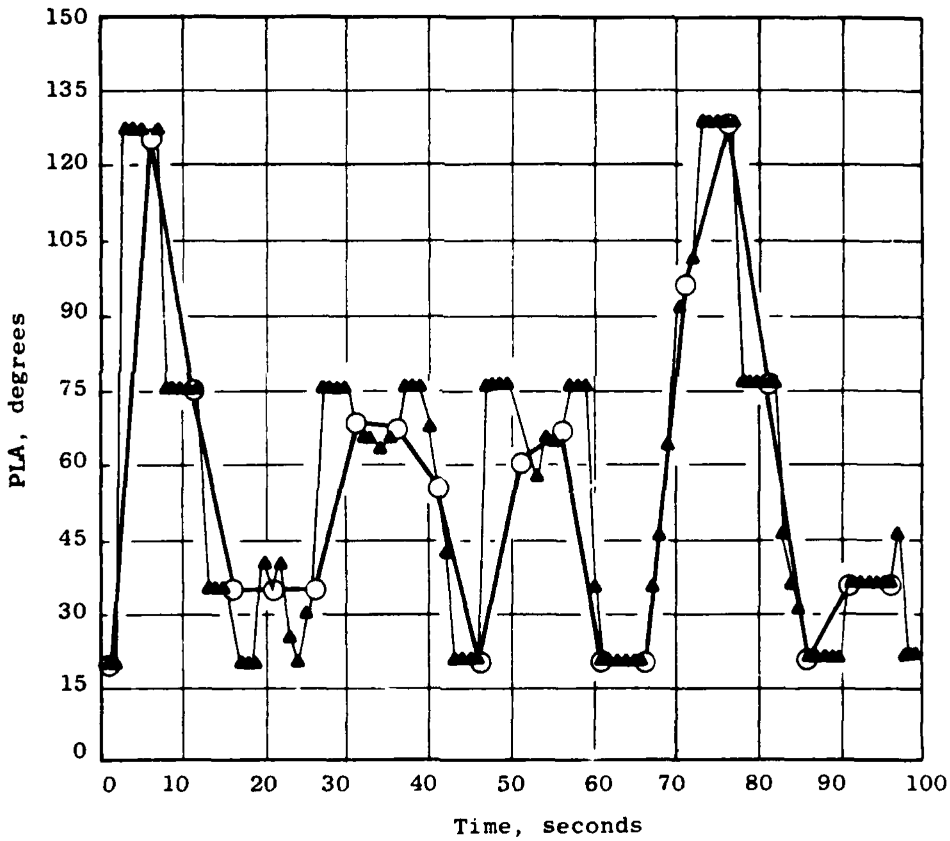


Figure 52. Example of Engine Usage Tracking Data Sampling Rate.

- TAMP ("Time at Max Power" which is considered as intermediate and above in augmented engines) would be calculated to be 31 seconds or 31% of the data sample using 1/sec data. The every-5-seconds data shows 15 seconds of TAMP plus any time period immediately before the first or after the last data point you wish to consider TAMP. If you assumed you were at TAMP for the full 5-second period after the last data point and for no time prior to the first data point, you would calculate TAMP to be 25 seconds for an error of 19.4%.

If engine usage data are to realize its full potential in supporting a weapons system maintenance program, the data must be accurate and complete.

Usage tracking software should not be part of the aircraft system, since all the critical modes or unique conditions that may become very important in scheduling required maintenance will most likely not be known at the time of introduction of a new weapons system. If all data reduction is done by ground computers, the data can be reprocessed after a new critical mode is identified, and engine maintenance schedules can be adjusted as necessary.

SECTION XI

FALSE INDICATIONS

The CITS development has been hampered by the many false alarms early in the program (about 100/flight) and the credibility of CITS has suffered as a result of this less-than-impressive beginning. Most of the problems responsible for false alarms have been software-related. Compounding this problem is the excessive time that has been taken to implement software changes.

The number of false alarms in the propulsion area, of which the engines are the major component, started out at slightly less than 50 per flight. This number has been reduced down to one or two per flight, depending on the aircraft and the engine type. Note that one false alarm per flight means that each engine will output the same false alarm during a flight.

One of the biggest problems in connecting the software has been identifying the test that was responsible for the output message. There are approximately 115 to 120 tests that can cause one of the 20 standard fault messages to be outputted. Had each test that could cause an output been assigned a unique number and that number been outputted with the fault message, it would have greatly facilitated software problem identification and correction.

Reducing the time to implement software changes in the CITS would be very beneficial, not only to the false alarm problems, but to the entire CITS development program. A rapid reduction to zero in the number of false alarms without jeopordizing the accuracy, completeness, or purpose of the tests should be given the highest priority if the CITS or any other condition monitoring program is to gain the much needed acceptance of the weapon system users - the pilots and crew chiefs.

SECTION XII

CONCLUSIONS AND RECOMMENDATIONS

The CITS has successfully demonstrated that a complex engine condition monitoring system can be developed as a vital part of a modern weapons system. With continued development, CITS would be capable of meeting all its contract goals. It is presently meeting its most important goal of accurate fault detection for 95% of all faults experienced.

Many lessons have been learned in the development of the B-1/F101 CITS. This report will draw conclusions and make recommendations for future development of the CITS and more general conclusions/recommendations applicable to future engine condition monitoring systems or usage tracking systems based on this experience base.

- Fault Detection. Limited in-flight capability mainly to detect and record limit exceedance events.
- Fault Isolation. To be performed postflight using ground computer system and data from the "fault detection" event.
- Usage Tracking. Necessary on any system including tracking of low cycle fatigue, thermal cycles, and time at high temperatures. This information will also be used as input to any comprehensive engine management system.
- Trending. Overall engine health monitoring through limited data, i.e., NF, WF, T_4 acquired at one to two high power and repeatable flight condition, i.e., takeoff.

A. FAULT DETECTION

CITS has demonstrated that accurate in-flight fault detection can be accomplished. The present CITS would have detected 100% of the mature engine faults (mission power losses) in the B-1 Flight Test Program. Of the total 29 faults studied by this report (15 mature, 14 immature), the CITS would have accurately detected 26 faults or 89.7%. The three faults not detected by CITS were augmentor pump fuel leaks (out the engine overboard drain) which CITS was not intended to detect. Excluding these fuel leak events, the current CITS would correctly detect 100% of the 26 remaining faults.

1. Fault Data

The fault detection function of CITS has been very successful in meeting its goals. In support of the detection function is the data recording that accompanies each fault detection output. The data obtained by CITS have been invaluable in isolating problems, often without requiring additional engine runs, and in support of engine troubleshooting activities when engine runs were required. There is one basic change, however, that should be made to make these data even more useful in identifying the cause of a fault. That change is the introduction of a recording buffer.

The CITS or any future system should have an internal data storage area (buffer) where the previous 8 to 10 seconds' (32 to 40 data slices) worth of data could be temporarily stored. With this data buffer, it would then be possible to record the 4 or 5 seconds of data immediately before and after the time the fault was actually detected. In the present system, the data recorded are taken 0.25 second after the fault was detected; and in many cases, the fault-producing condition does not show up in the data. With the recommended system, this would never be the case.

2. Value to Air Crew

With the exception of the simple limit exceedance faults associated with the existing cockpit indicators which should have a redundant limit exceedance annunciation system of their own, it is questionable whether the air crew would find some of the more subtle fault detections having to do with incipient-type failures or problems associated with the engines control systems of value. This second type of information is invaluable to the ground crew, for it enables them to take corrective maintenance actions, prior to the next flight, that will assure these subtle problems do not lead to MPL faults. This, of course, is of the utmost importance in single-engine aircraft.

It is recommended that the value to the air crew be established for future systems by pilot interviews and review of accident/incident records to see if such additional data availability could have altered the outcome of the event. In any system that is chosen it is important that all fault detections and their accompanying recorded data be readily available to the ground crew upon landing.

3. No Substitute for Visual Inspection

Even the most elaborate fault detection system can never be a substitute for thorough visual inspection. Fluid leaks (other than lube oil), FOD, or mechanical failures are not likely to be detected by a condition monitoring system until the condition has deteriorated to the point beyond which continued operation could cause major engine damage.

Of the 139 engine removals during the period studied by this report, 63 were removed because of faults/conditions detected visually; 22 were removed because of the more subtle types of operational problems or failures that the CITS would detect; and the remaining 54 engines were removed for convenience.

B. FAULT ISOLATION

CITS did not meet its goal that 75% of all faults be isolated to the correct LRU (Line Replacement Unit). Of the 14 mature faults, it correctly isolated 10 for a success rate of 71.4%. For the 15 immature faults, CITS only isolated correctly three times (20%). For the total 26 faults (which excludes the 3 augmentor pump fuel leaks), CITS had a correct isolation rate of only 50%.

Where Fault Isolation Should Be Done

Where fault isolation should be done must be answered when future condition monitoring systems are still in the conceptual stage. To help decide, the following observations are offered:

- The CITS isolation goals could be met if additional computer capacity were made available. The isolation capability of CITS could also be enhanced by the addition of two new data sensors to the engine, i.e., VSV and T_{25}.
- The isolation data are of little or no value to the air crew while the aircraft is in flight.
- The weapons system turnaround time criterion must be closely analyzed to determine if it justifies the added complexity and computer capacity to make fault isolations in the air. On the ground, a larger computer could readily process the data and do a more thorough analysis.

- If no provision for fault isolation is made, either by the aircraft computer or by a local ground computer, highly trained personnel must be available for data analysis at each base.
- If isolation were done on the ground by a larger capacity computer, the number of engine parameters recorded could be reduced slightly.

It is the recommendation of this study that future condition monitoring systems perform the fault isolation function in a ground computer.

C. FLIGHT READINESS

The CITS has demonstrated its capability for accurately determining whether there is adequate thrust available for takeoff. It has been difficult to make judgments on the in-flight, engine-to-engine thrust comparison method of determining flight readiness since no detection of low or high thrust could be located for analysis.

1. Ground Thrust Determination

In order for ground thrust to be compared against a limit curve, it had to be determined accurately. The biggest problem was in handling the effects of installation and engine-to-engine variation. Unfortunately, a fairly large sample of actual data must be used to be able to generalize the actual installed-engine performance and its relationship to test stand data. Generally, a ground thrust flight readiness test can be successfully performed by CITS or a future system. But considerable development effort will be required to achieve the desired accuracy and to determine the correct installed-engine limits.

2. PLU - An Alternate Flight Readiness Approach

The power level unit (PLU) gage used on the B-1 aircraft has proved to be an excellent alternative to the CITS flight readiness approach. Although this gage is not simple, it has been reliable and is valued by the pilots as the key engine parameter during takeoff. It is recommended that future applications of augmented turbofan engines include this valuable instrument in their installation plans especially in single engine aircraft.

D. LOW CYCLE FATIGUE CYCLE AND TIME-AT-TEMPERATURE/SPEED COUNTING

So far, the CITS has failed to accurately capture LCF or time-at-temperature/speed data. This failure is primarily due to software problems that have not been given the attention they deserve considering the importance of these sets of data in determining when engine maintenance actions will be required. Fortunately, however, the LCF and time-at-temperature data were successfully extracted from the CITS flight test data tapes by postflight processing. While not completely accurate, this method has been of considerable value in the B-1 Flight Test Program.

1. LCF Data

This set of data is one of the prime inputs to any minimum engine usage tracking or maintenance scheduling techniques envisioned for the F101 engine or its derivatives. The LCF data must be accurately captured and recorded if this function of the CITS is to be considered successful. Two features are, therefore, essential: (1) the CITS must have a large enough recording capacity to record all LCF data; and (2) the CITS must not be able to be shut down by the envelometer or a similar device, so that data are no longer lost.

Any future system, whether condition monitoring or engine usage tracking, must include provisions for capturing complete and accurate LCF data, which will undoubtedly be a prime input into that engine CEMS (Comprehensive Engine Management System).

2. Time-At-Temperature Data

The only time-at-temperature data recording CITS was to have made was during conditions of turbine blade overtemperature events, and then only for the duration of the event. This approach would not be adequate for a production program. Although this set of data would be useful in making metallurgical judgments on hot section parts that appeared visually to be sound after an overtemperature event, what is needed is a system that records the total elapsed time at rated turbine temperature (red line time).

It is recommended that CITS or any future system be required to include, as a minimum, a counting of the total time at red line conditions. The continuous recording during overtemperature events should be maintained if it can be incorporated without significantly affecting the recording capacity of the system.

Like the LCF data, the time-at-temperature data would be a prime input to the engine CEMS. If the CEMS is to be effective in scheduling maintenance activity, these two types of data would be the minimum required.

E. ENGINE TRENDING

The CITS has been effective in recording trend data from the selected trend windows. While this kind of data has not been utilized to the fullest extent possible, the data appear to be of good quality. Moreover, the logic directing their recording also appears to be working as intended.

1. Manual Trending

The manual trending technique that was developed uses only five parameters from postflight runup data. Though relatively simple, this technique has proved to be an effective method of determining engine performance level during the B-1 Flight Test Program. Based on the results of this trending, maintenance decisions have been made, i.e., decisions regarding which engine to install for a given flight where maximum performance was required or which engine to send to the shop for performance restoring component replacement.

The effectiveness of this approach is probably limited to the flight test phase of a program, but the experience gained here can serve as a vital link in tying the test cell performance data to the installed takeoff and climb performance data that will ultimately be used in a production program to trend the engines.

2. Automated Long Term Trending

The DALTT (Diagnostic and Long Term Trending) program was developed and verified during endurance testing as the starting point for developing the long term trading module for the F101 CEMS. If the B-1 program had not been cancelled, work would have continued on the development of a long term trending for the CEMS through the efforts of GE and USAF/OC-ALC personnel.

Using the limited amount of work that was done in this area after the cancellation of the B-1 program, it was determined which parameters were required, and it was decided that the number of trend windows could be reduced from five to two. It was also determined which engine and aircraft parameters would most enhance the effectiveness of long term gas path trending.

Two questions must be answered in planning a future system: (1) can an effective module tracking system be developed using gas path trending and (2) if so, will it be cost effective. Unfortunately, these questions will not be answered in the existing B-1 Flight Test Program.

F. MAINTENANCE ACTIONS RESULTING FROM CITS

The CITS has not been a good indicator of required maintenance actions through this state of development. Too much time is required to incorporate required software changes. It now appears that in future flights on A/C 4 (Flight 4-12 and following) the close-to-100% fault detection CITS is capable of will be realized. The isolation of faults to a correct LRU should also improve but it appears that CITS will fall short of its goal of 75% correct isolations.

The CITS flight test data tapes have, however, been an invaluable source of engine usage data that have been used to schedule engines into the shop for life-limited component replacement or rework. The CITS data have also been an invaluable aid in troubleshooting.

1. Maintenance Directly Resulting From CITS

Of the 22 engine-caused removals that were not the result of visual inspections, only 4 were detected by the CITS software in place at the time of the incident. All four of these events were related to the lube system - two gulping incidents leading to MPL's, and two lube leaks that were the result of cracked fan frame struts.

There were numerous incipient or subtle failures that were correctly identified by CITS, but records that would be needed to quantify this type of events are not readily available. One reason is that during grounds runs it has not been the practice to utilize the CITS or to record CITS flight test data. As a result, information is lacking on 10 CITS-identified faults that resulted in engine removal.

2. Maintenance Resulting From CITS-Acquired Data

One of the invaluable data sources in the B-1 Flight Test Program has been the CITS flight test data tapes. From these tapes, it has been possible to extract LCF and time-at-temperature data that have proved very useful in scheduling engines maintenance actions.

Being able to acquire CITS data via the CCD parameter monitor has been an invaluable aid in troubleshooting engine problems. If this capability had not existed, the engine removal rate for troubleshooting purposes alone would have been greatly increased.

3. Future Flight Test Programs

In future flight test programs it is recommended that, if at all possible, continuously recorded data similar to the CITS flight test tapes be obtained from the first flight until such time that the engine condition monitoring and usage tracking systems have been developed to the point where they can be relied on to accurately collect all required fault and engine usage tracking data.

In smaller, single- or twin-engine aircraft, it is unlikely the parameter monitor function available in the CITS CCD would be available. For this reason, it is recommended that an AGE suitcase-type unit be developed to provide the capability of obtaining all required data for effective engine troubleshooting during ground runs.

G. SENSOR SELECTION

The CITS sensor selection for the engines was adequate for fault detection purposes, but the fault isolation function could be enhanced by the addition of two additional engine sensors - one for core inlet temperature (T_{25}) and the other for core engine variable stator vane (VSV) position. A similar enhancement to gas path trending could be made by the addition of a compressor discharge temperature (T_3) sensor to the engine and a bleed flow indicator to the aircraft.

All sensors selected with the exception of the aircraft-supplied fuel flow sensors, demonstrated adequate accuracy, repeatability, and reliability for the purposes they were intended to serve in the engine CITS. The only problem with the fuel flow measuring system was instability around a flow point.

H. DATA SAMPLING RATE

The data sampling rate selected for the engine CITS test of 4/sec appeared to be close to optimum for the dynamic characteristics of the system being monitored.

I. ENGINE USAGE TRACKING

One of the truly unexpected benefits of the CITS in the B-1 Flight Test Program was the wealth of engine usage tracking data that was obtained. Although the quantity of data obtained by CITS would be overwhelming for usage tracking purpose alone, it has supplied a data base from which specific recommendations for future systems can be drawn.

It is recommended that all future applications of advanced technology augmented turbofan engines, such as the F101 DFE, include an onboard engine usage tracking system that is capable of continuously recording six parameters, one of which is time, at a rate of one data slice per second.

J. FALSE INDICATIONS

The false indication rate in the B-1 CITS has hampered the total systems development and led to early CITS credibility problems. The one recommendation that can be made for continued CITS development or any future systems development is that the time required to make system software changes must be minimized.

K. LESSONS LEARNED

The following observations and recommendations are offered to those responsible for guiding the conceptualization, planning, and development of future engine condition monitoring systems:

- Size the onboard computer so that substantial excess capacity exists at the beginning of the development program.
- Give careful consideration to whether a function such as fault isolation can be done better in the air or on the ground.
- A condition monitoring system should start its development while the engine is still in the factory test phase of its development. The condition monitoring system should be introduced early in the flight test program (for the first flight if possible).
- The time required to make needed software changes in the development program must be minimized.
- If timely fault evaluations are to be made, an effort must be made to reduce the data transfer time between the condition monitoring system contractor or aircraft contractor and the engine contractor. Unnecessary changes in data format should not be made without adequate, prior coordination between all using parties.

LIST OF ABBREVIATIONS AND SYMBOLS

Symbol	
A/C	Aircraft
AEDC	Arnold Engineering Development Center
A_8	Exhaust Nozzle Area
AFF	Aircraft Total Fuel Flow
AFTC	Augmentor/Fan Temperature Control
AGE	Aircraft Ground Equipment
AMT	Accelerated Mission Test
A/V	Air Vehicle
CCD	CITS Control and Display
CEMS	Comprehensive Engine Management System
CFF	Core Fuel Flow
CI	CITS Interface
CITS	Central Integrated Test System
CITSP	CITS Processor
DALTT	Diagnostic and Long Term Trending
DAU	Data Acquisition Unit
EIS	Engine Instruments Subsystem
EMUX	Electrical Multiplex
EPR	Engine Pressure Ratio
FF	Augmentor Fuel Flow
F_g	Gross Thrust
FOD	Foreign Object Damage
FPR	Fan Pressure Ratio
FTE	Flight Test Engineer
GEEFTC	General Electric Edwards Flight Test Center
GMT	Greenwich Mean Time
GPS	Ground Processing System
HPT	High Pressure Turbine
HTFT	High Through-Flow Turbine

Symbol	
IGV	Inlet Guide Vane
LCF	Low Cycle Fatigue
LRU	Line Replaceable Unit
MEC	Main Engine Control
MPL	Mission Power Loss
NC	Core Speed
NCREF	Reference Core Speed
NF	Fan Speed
OPSEV	Operational Severity Analysis (Computer Program)
PLA	Power Lever Angle
PLU	Power Level Unit
P_{S3}	Compressor Discharge Static Pressure
P_{T2}	Fan Inlet Total Pressure
PWFR	Augmentor Fuel Pressure
Red Line Time	Total Elapsed Time at Rated Temperature
SAC	Strategic Air Command
SCDU	Signal Conditioning and Distribution Unit
S/N	Serial Number
TAMP	Time at Maximum Power
TC	Thrust Coefficient
T_{4B}	Engine Turbine Blade Metal Temperature
T_{25}	Core Engine Inlet Temperature
T_{TO}	Engine Inlet Temperature
VSV	Variable Stator Vane
WB	Warm Bridge
WUC	Work Unit Code
ZULU	Greenwich Mean Time

Special Definition

Envelometer - A device in the aircraft that is used to schedule the data tape recorders.

☆U.S.Government Printing Office: 1980 — 657-084/704

END

DATE
FILMED

8-80

DTIC